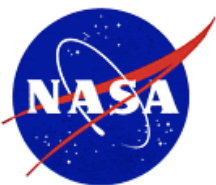
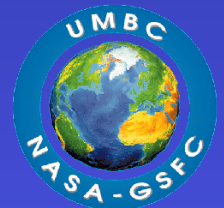


# Hunting Hurricanes: NASA's Field Programs Exploring Hurricanes Using Satellites, Supercomputers and High Altitude Aircraft

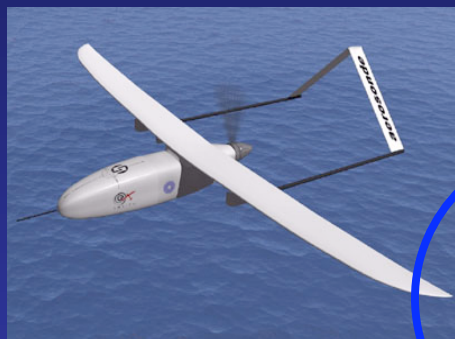


**Prof. Jeffrey Halverson**  
**University of Maryland Baltimore County**





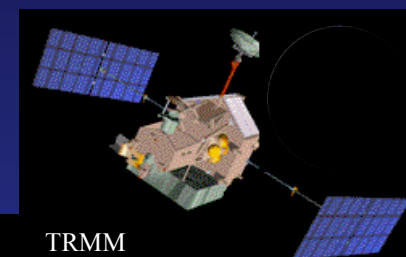
# RESEARCH SYNERGY



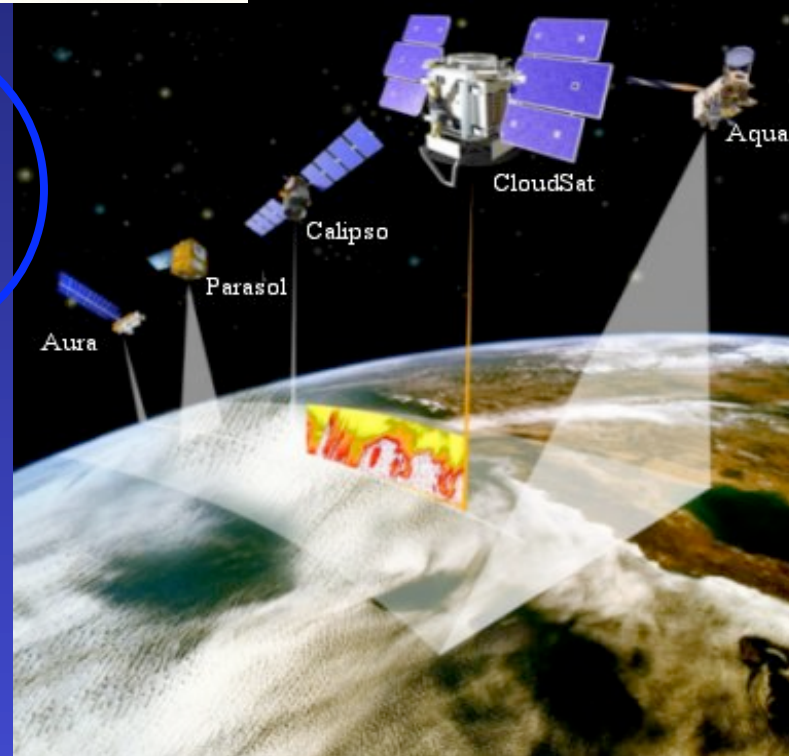
Models

Aircraft

Satellite



TRMM



Aura

Parosol

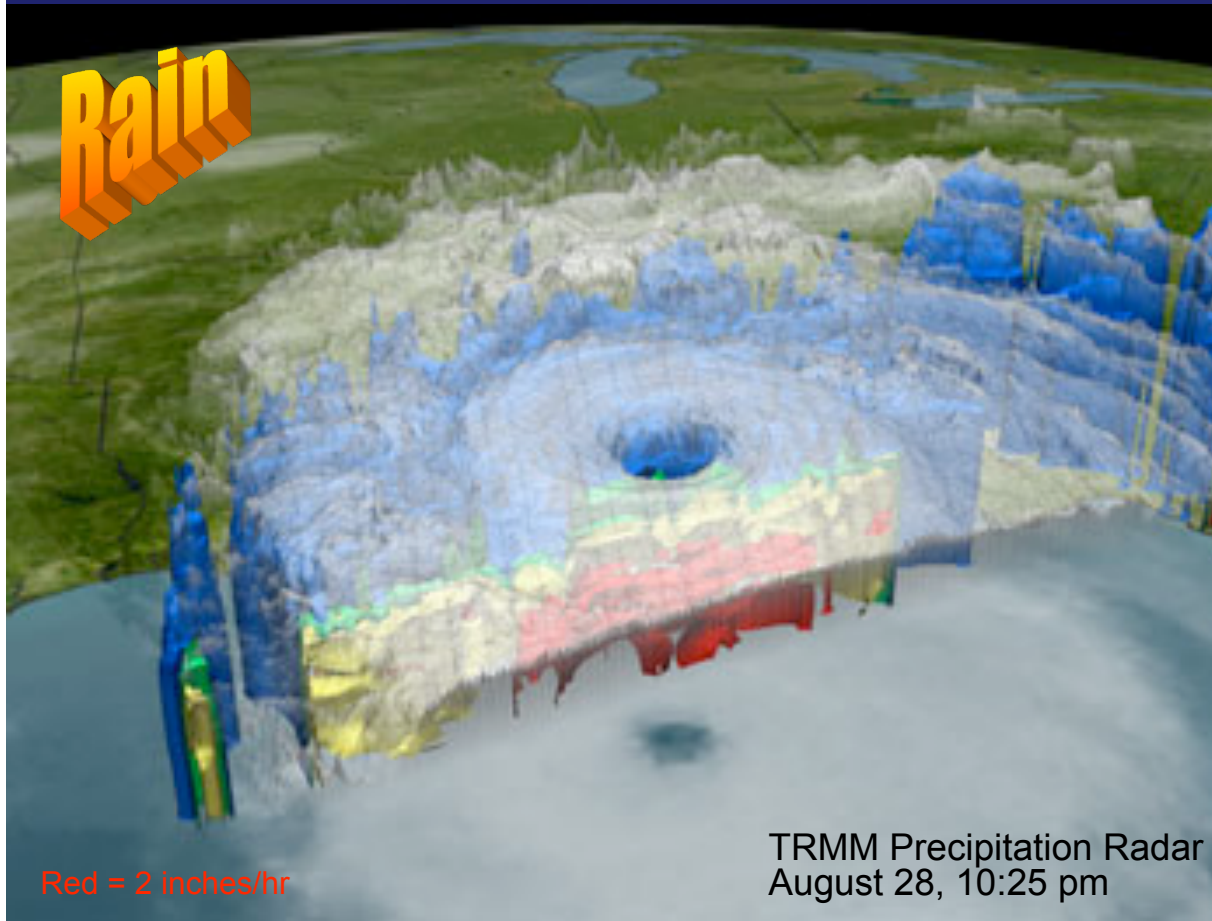
Calipso

CloudSat

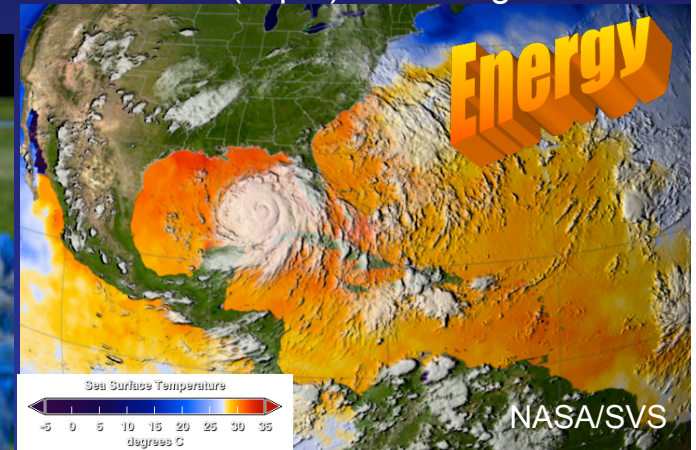
Aqua

# **NASA Satellite Investigations**

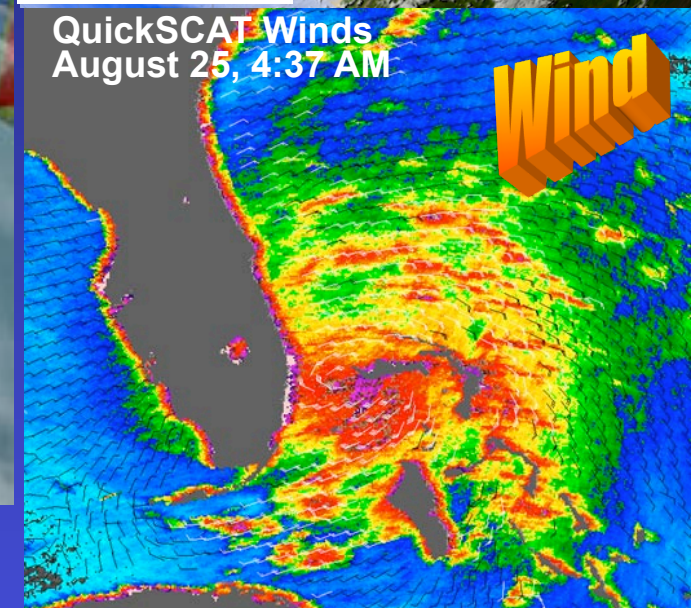
# NASA Earth Science Spacecraft Observe the Birth and Intensification of Deadly Category 5 Hurricane Katrina



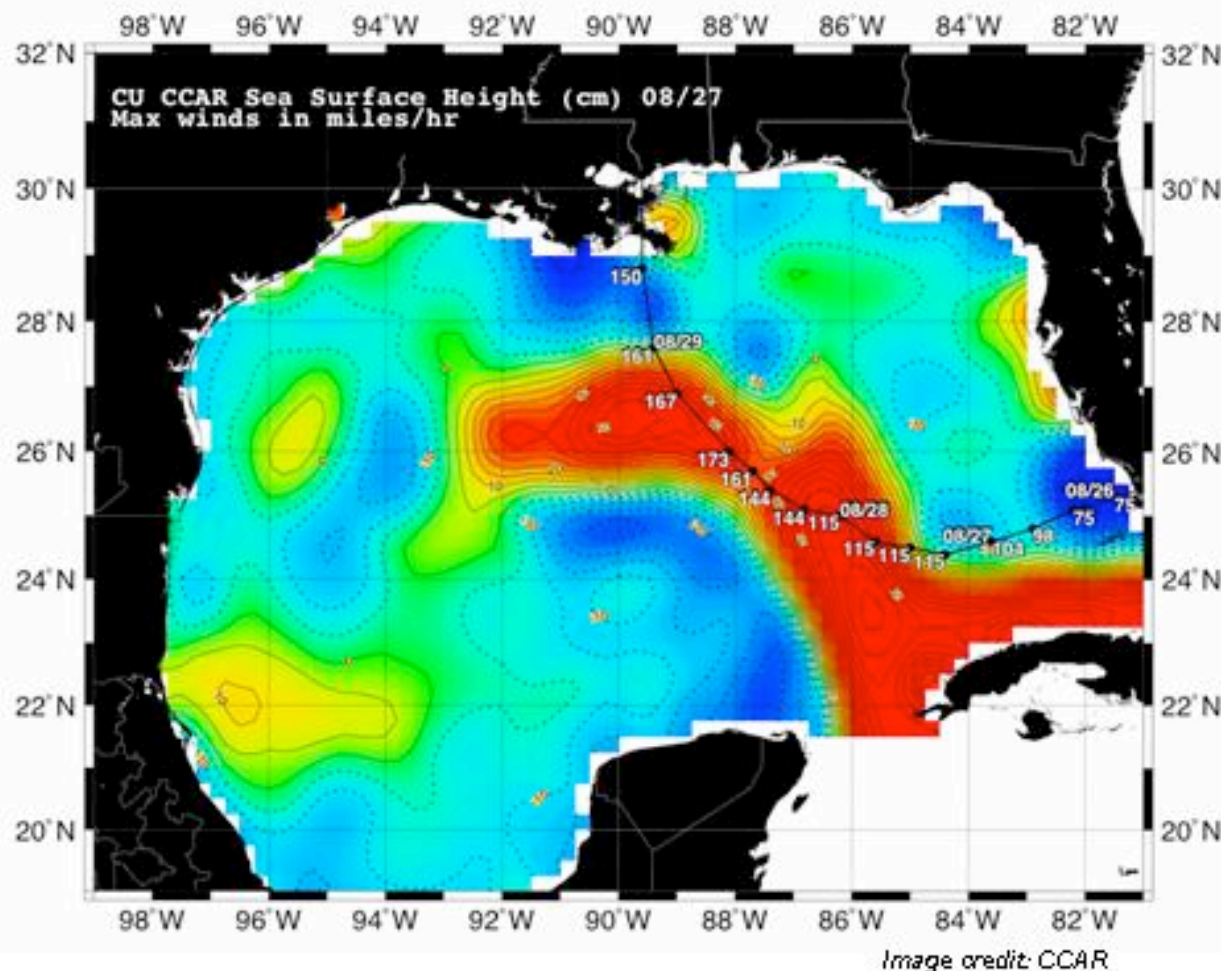
AMSR-E (Aqua) SSTs August 15-27



QuickSCAT Winds  
August 25, 4:37 AM



# Hurricane Katrina Heats up in the Gulf



SSH highs at the center of the Loop Current reached 50-70cm in this image from August 27, 2005. Wind speeds of Hurricane Katrina, indicated in white along the path of the storm, reached highs of 173 mph.

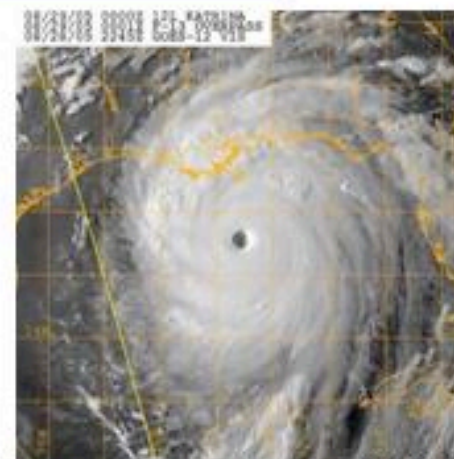


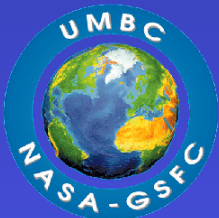
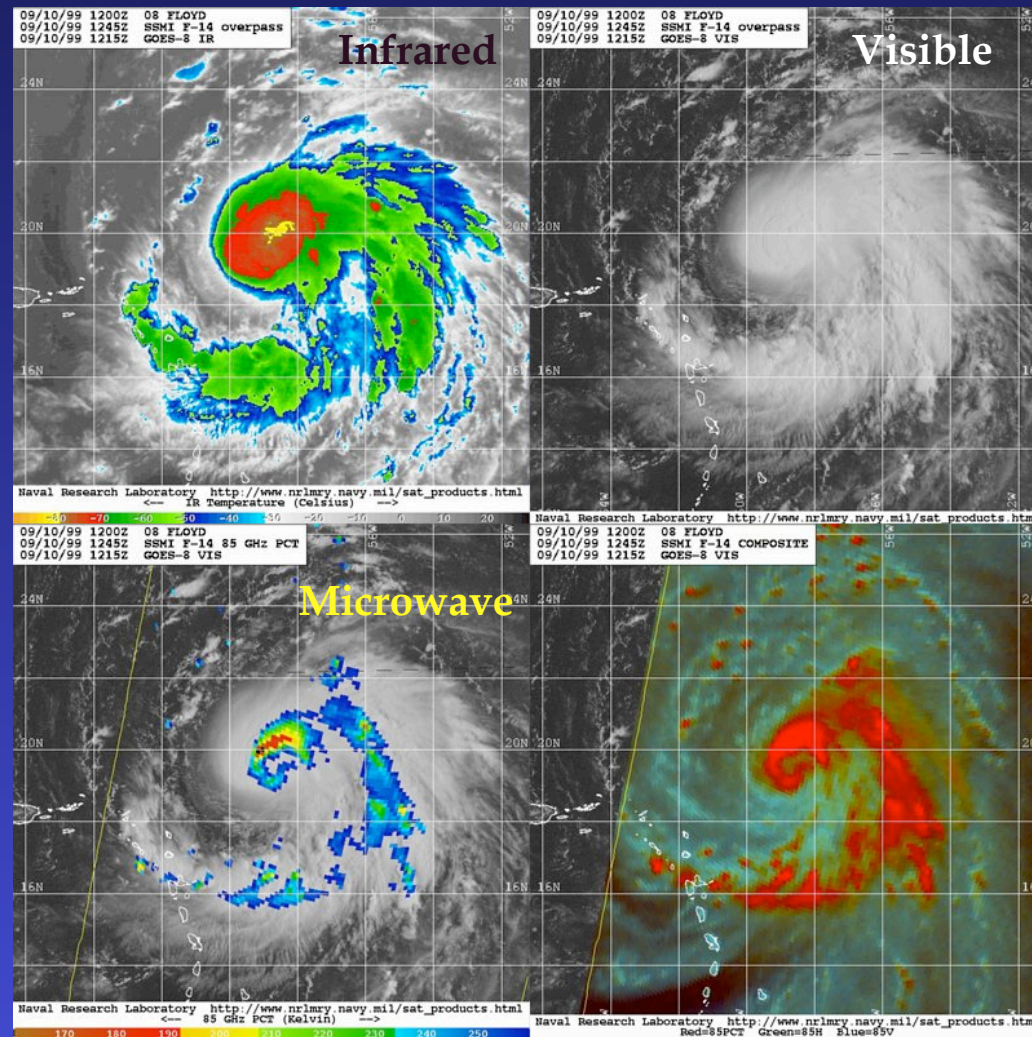
Image credit: NOAA

Maximum wind speeds of Hurricane Katrina increased dramatically as that storm passed over the warm waters of the Loop Current in the Gulf of Mexico in late August 2005. The storm evolved quickly from a category 3 to category 5 event in a matter of 9 hours as it drew heat from the Loop Current and a large warm core eddy evident in the sea surface height derived from merged TOPEX/Poseidon, Jason-1, GFO, and Envisat altimeter data processed by the Univ. of Colorado's CCAR group.

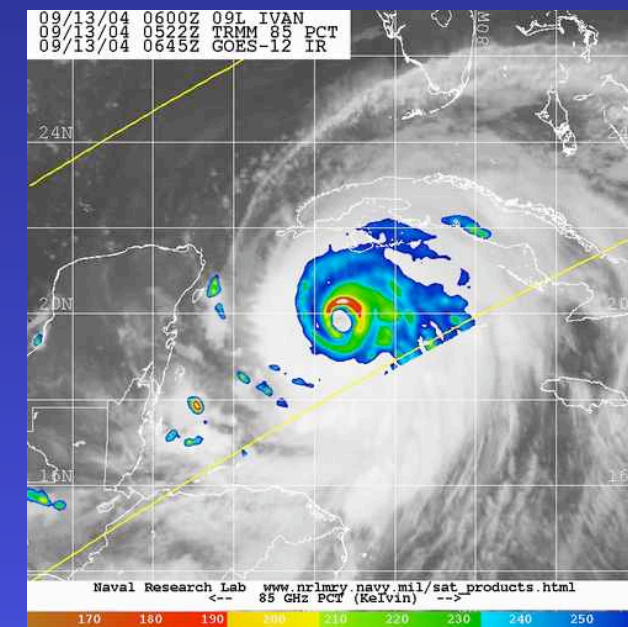
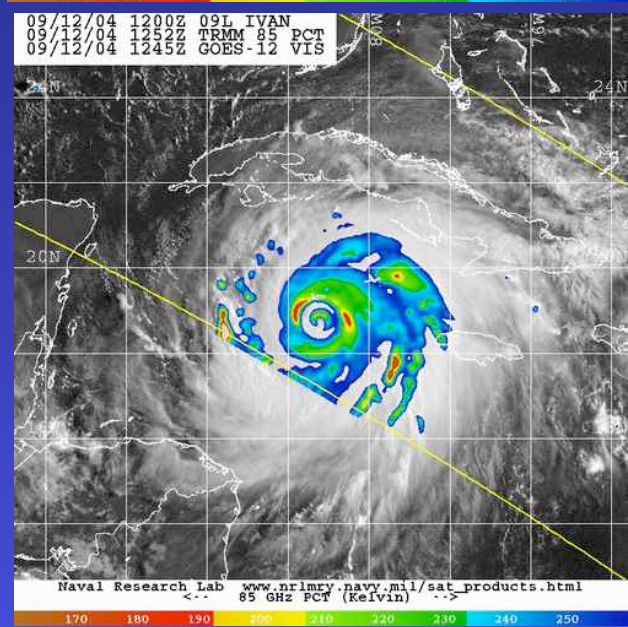
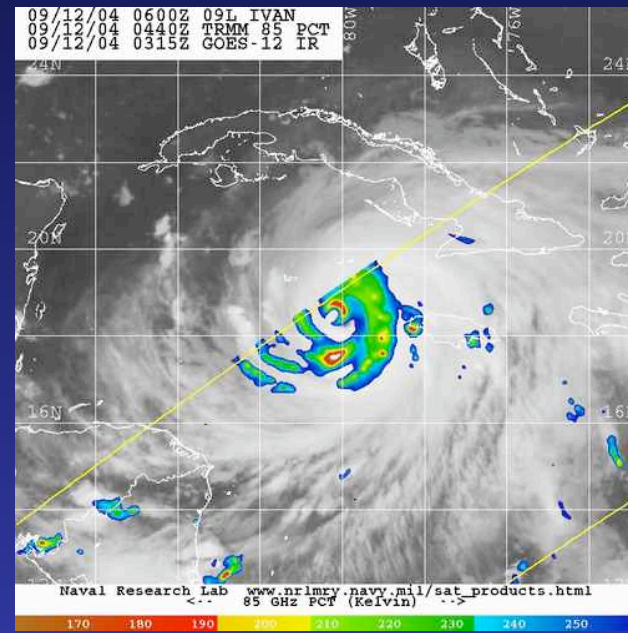
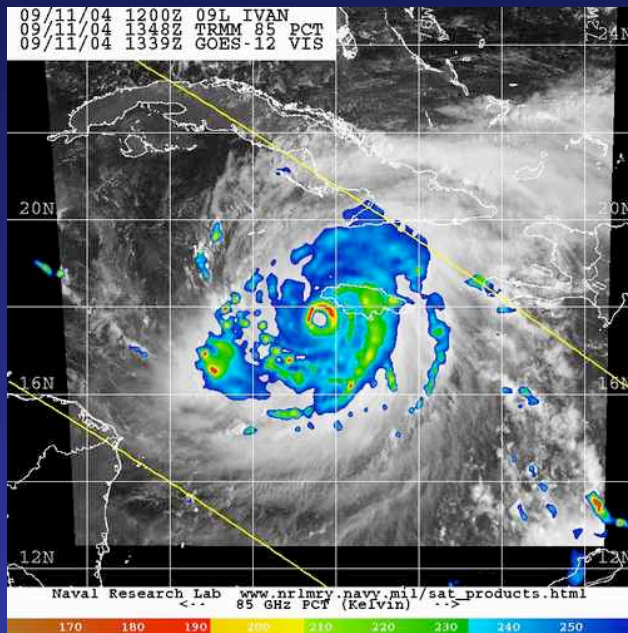
(R. Leben, G. Born)

# Hurricane Research: Advanced Satellites

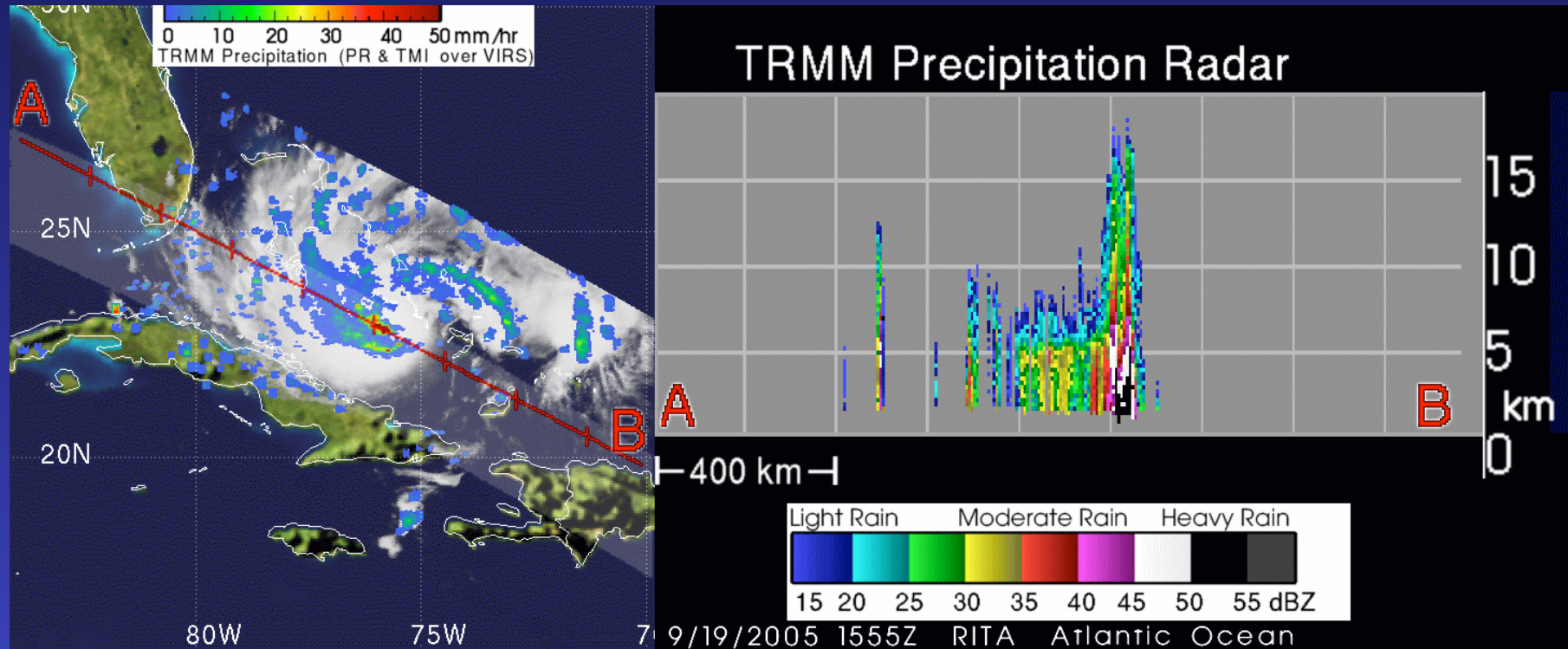
## TRMM Microwave Imager (TMI)



# TC Intensity Change - Sudden Weakening - Eyewall Replacement

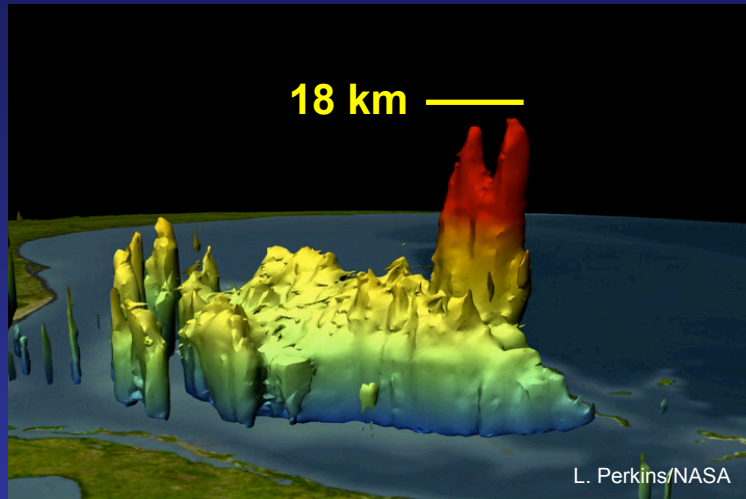


# Near-Real Time 3D Anatomy of Hurricanes



[trmm.gsfc.nasa.gov](http://trmm.gsfc.nasa.gov)

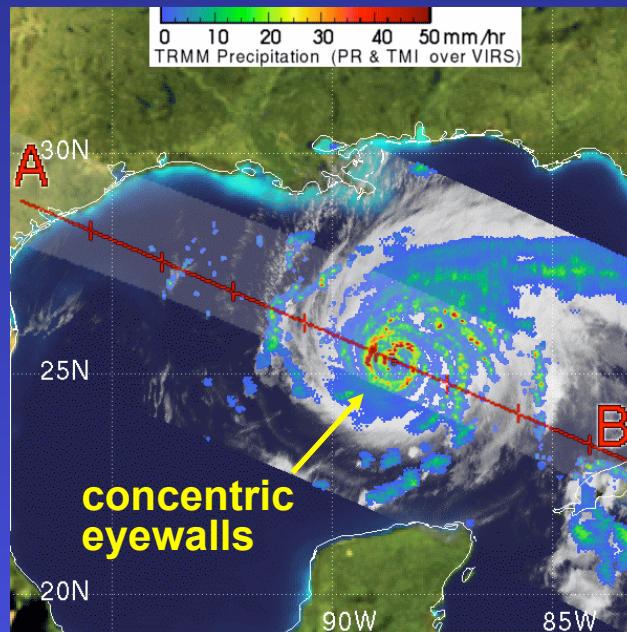
# TRMM Images Impressive Rain Structures in Hurricane Rita



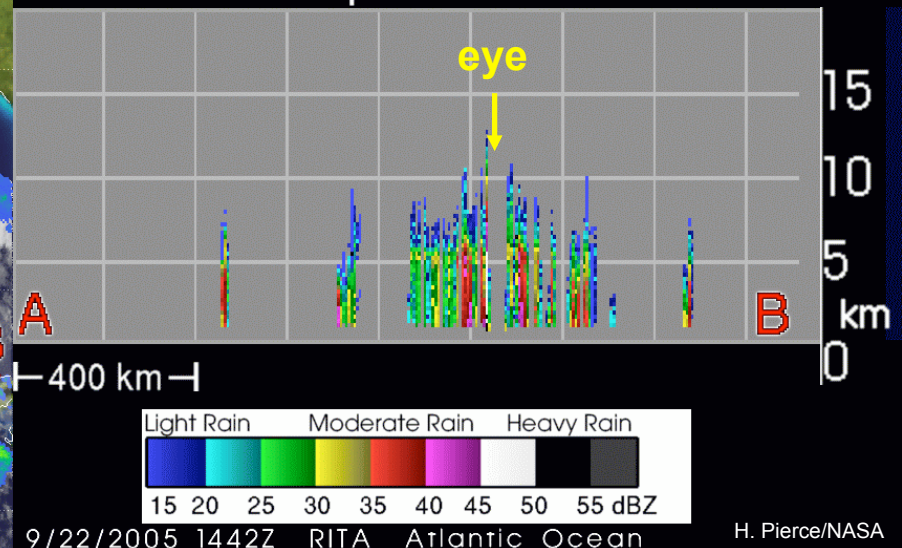
- Sept 19, 2005 - 3D rain isosurface of TS Rita
- Colors emphasize vertical height structure
- Twin 18 km deep hot towers fired off in first of two convective bursts in Rita's core presaging her rapid intensification
- This first burst occurred when Rita was positioned over 33° C SSTs in the Bahama Banks

Rita as Cat 5  
Sept 22, 2005

Eyewall  
Replacement  
Cycle (ERC)  
commencing

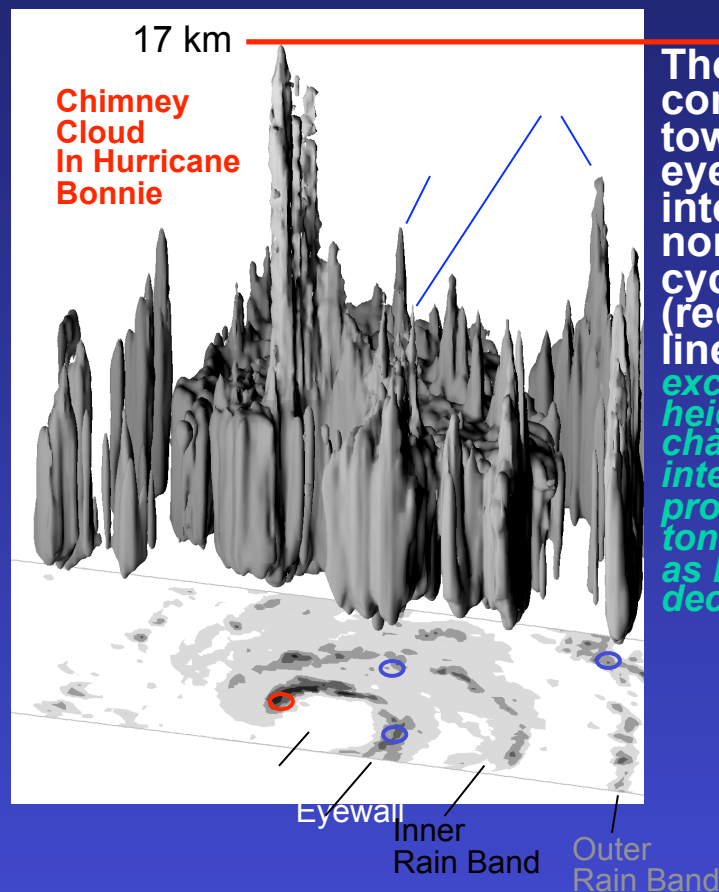


## TRMM Precipitation Radar

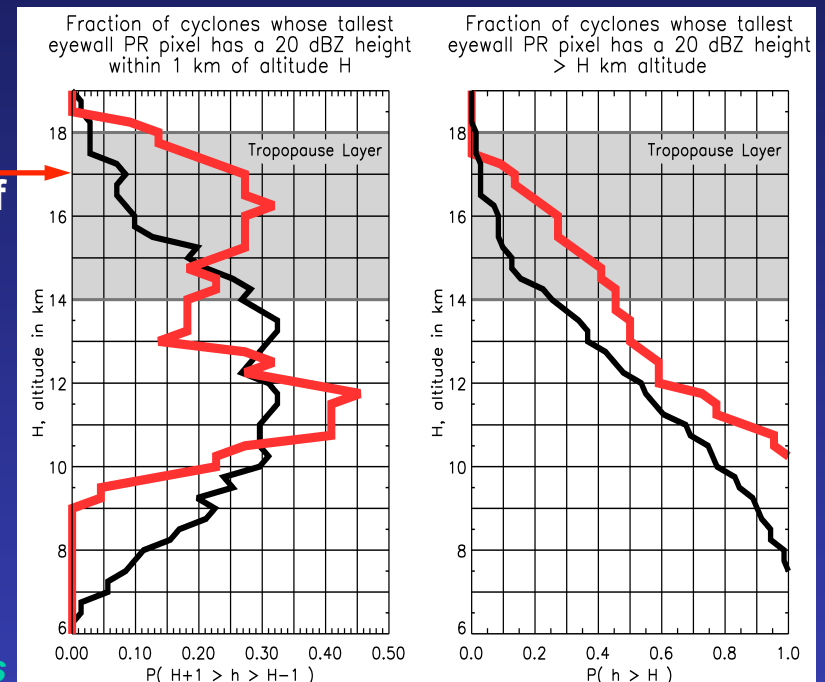


# TRMM Provides Clues On Hurricane Intensification

Unusually deep convective clouds hold clues to intensification.



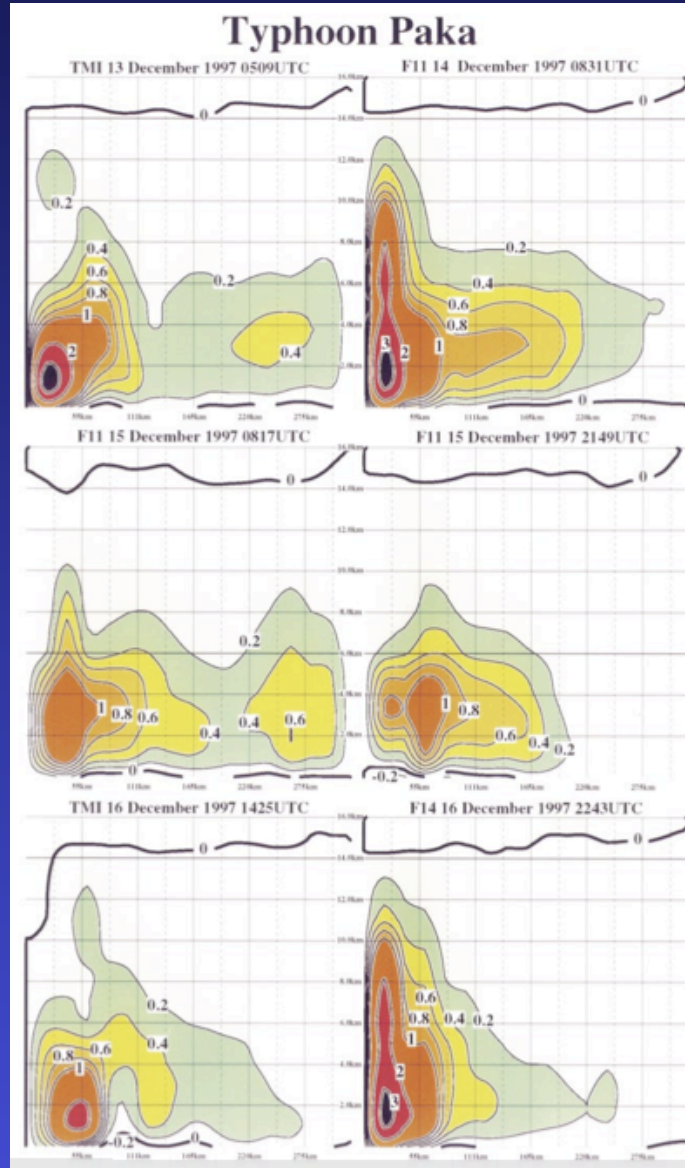
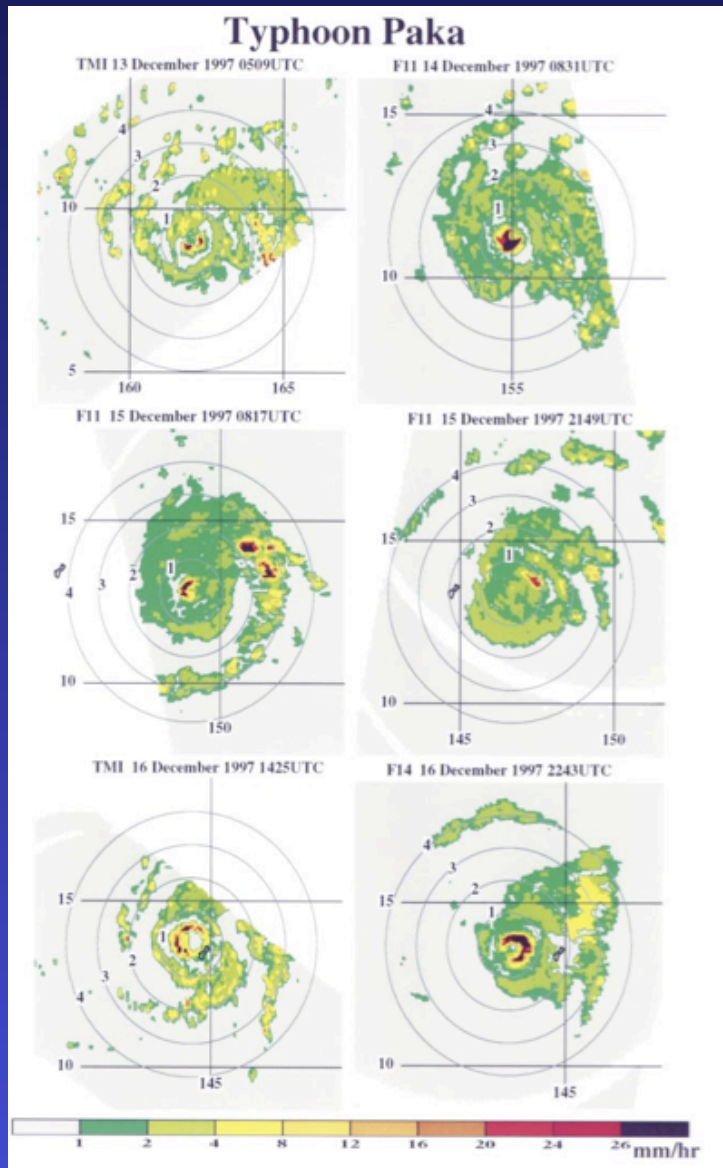
The frequency of convective towers in eyewalls of intensifying and non-intensifying cyclones (red and black lines) - towers exceeding 14.5 km height incur 71% chance of TC intensification; the probability monotonically decreases as hot tower height decreases.



- T.C. intensity is poorly understood & forecast.
- Intensification may be associated with unusually deep convective towers in the eyewall.
- The TRMM Precipitation Radar is the only instrument in space with sufficient vertical resolution to test this theory.

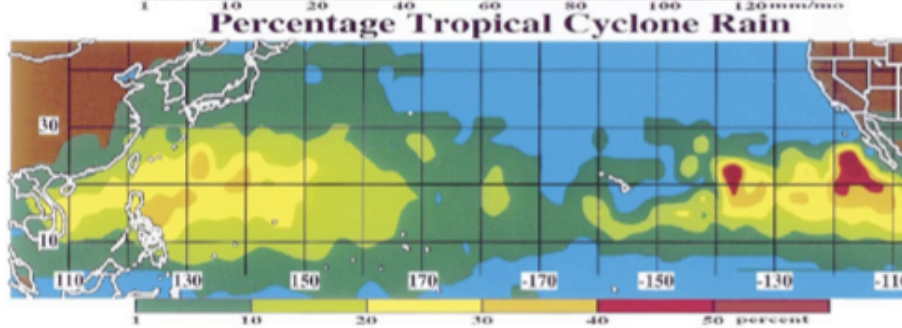
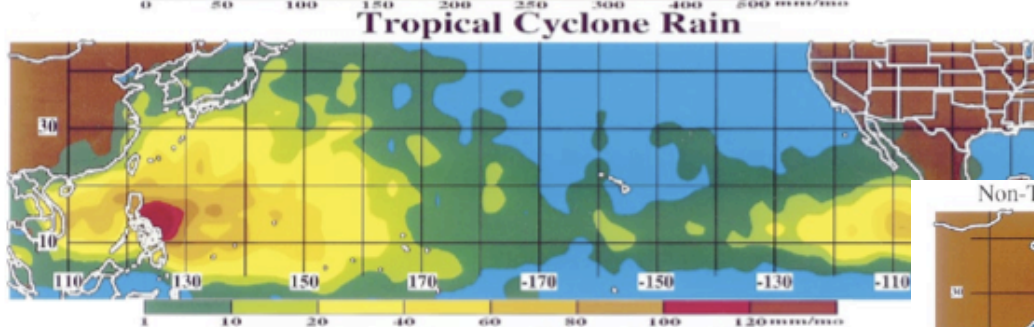
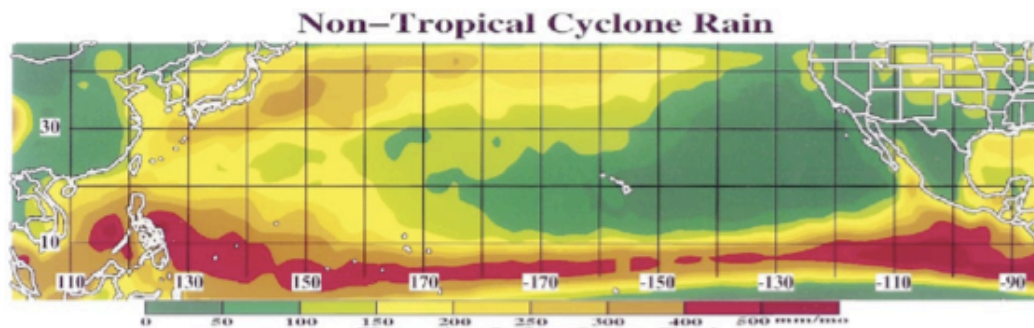
Kelly, Stout, Halverson, NASA GSFC

# Energy Release in Convective Bursts

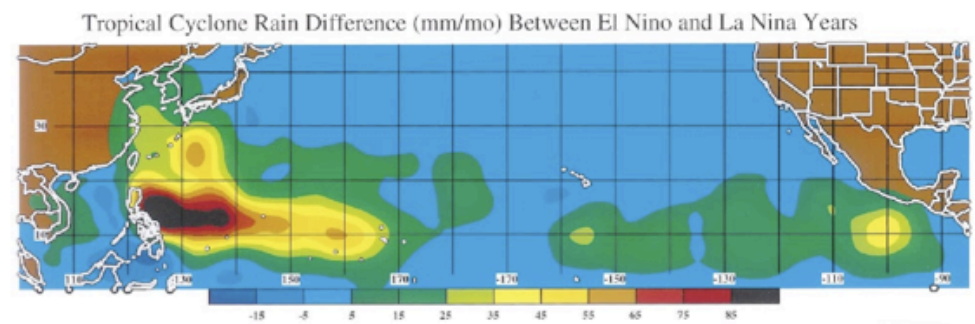
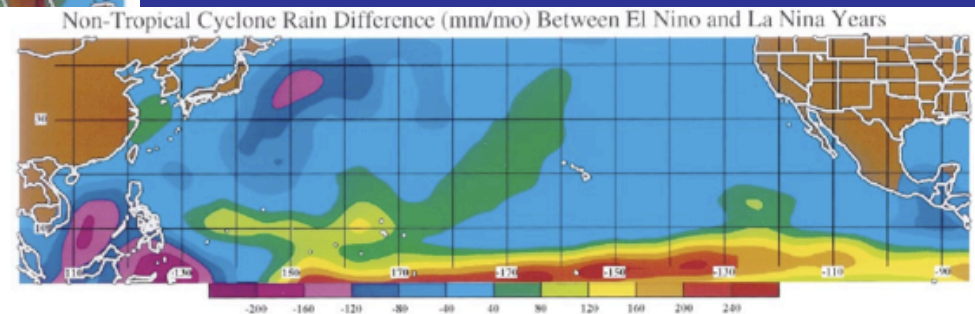


Ed Rodgers  
et al. 2000

# Contribution of TC Rain to Tropics

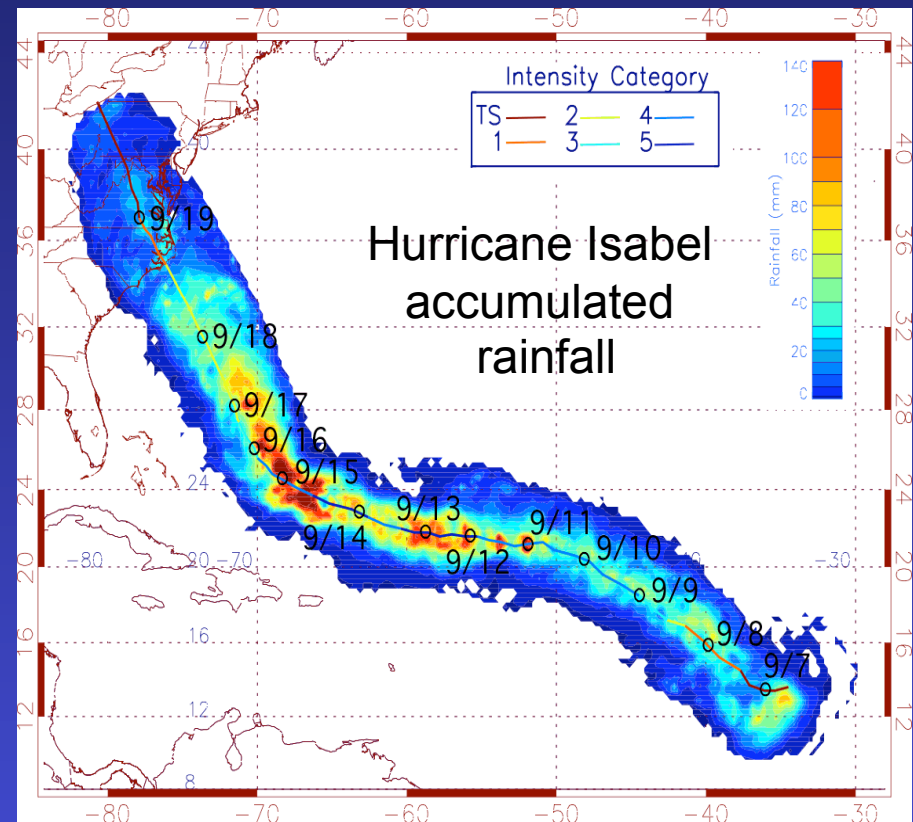
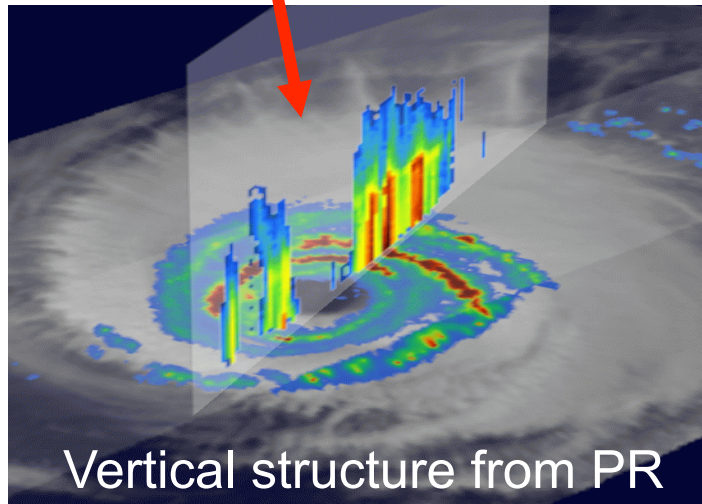
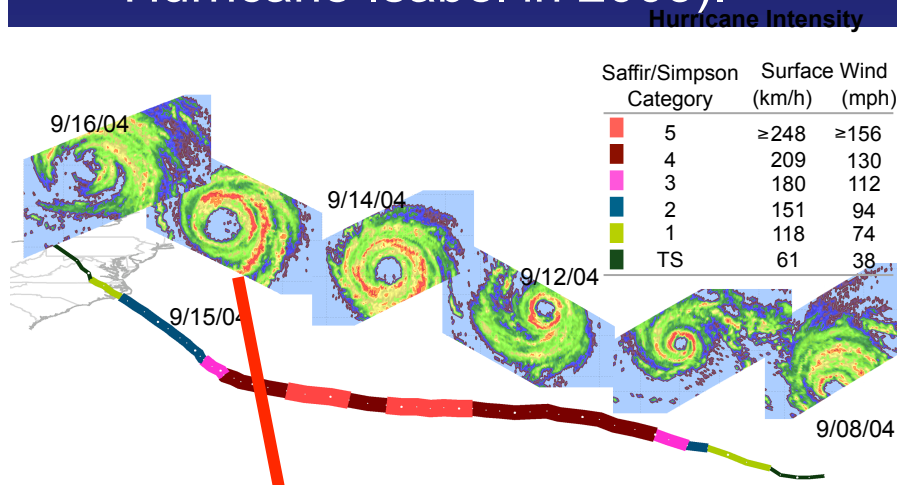


Rodgers et al. 2000



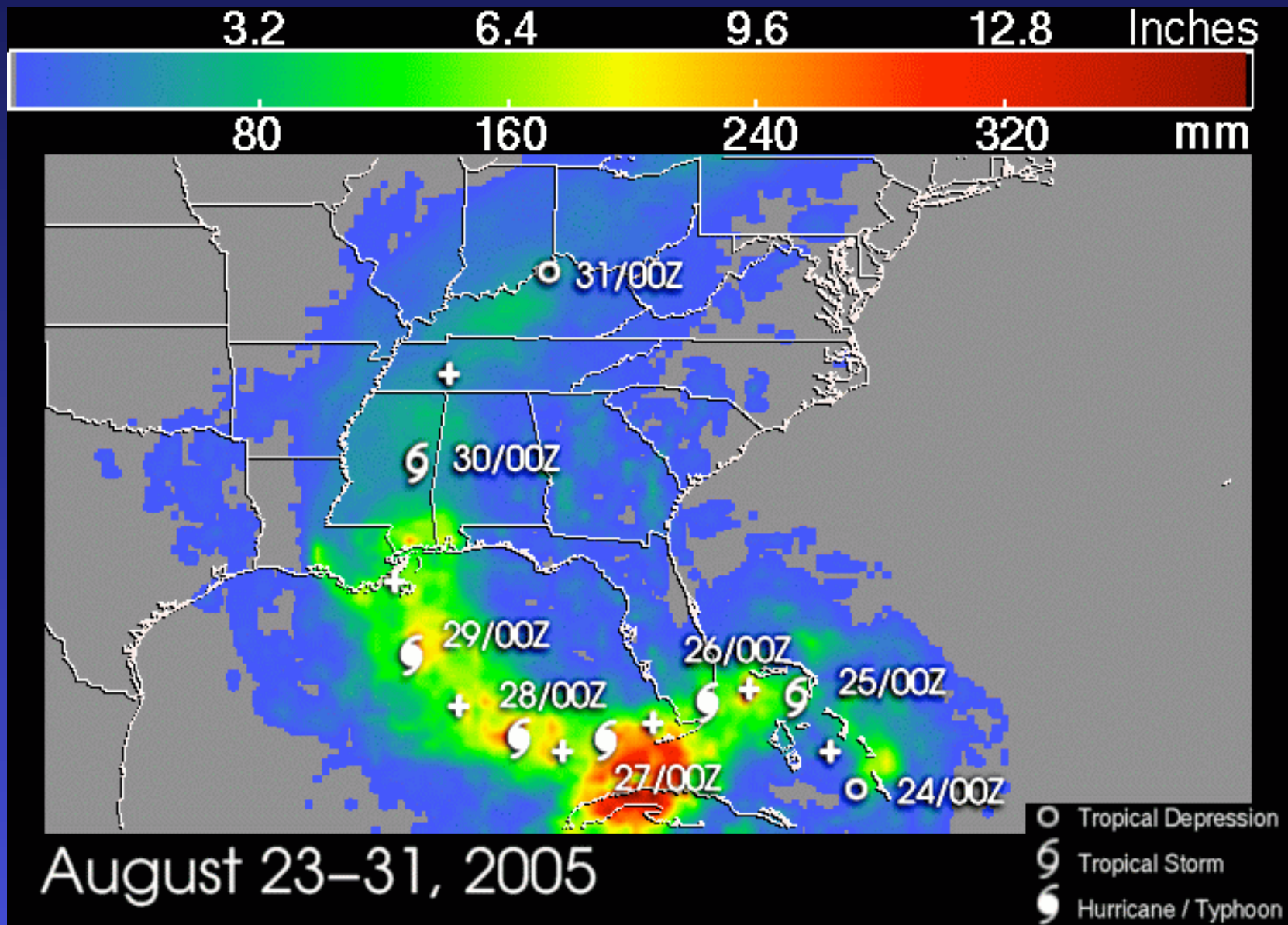
## TRMM Tracks Changes In Rainfall Structure and Accumulation

- By itself, TRMM provides detailed views of hurricane structure and structure change (example here is Hurricane Isabel in 2003).
- Combined with other satellites, the TRMM multi-satellite precipitation analysis (3B42) helps map rainfall evolution in hurricanes.

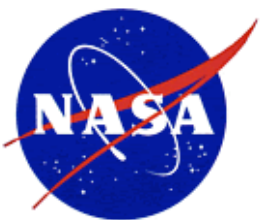


Available from <http://trmm.gsfc.nasa.gov/>

## Hurricane Katrina (2005) Multi-Satellite-Derived Accumulated Rainfall

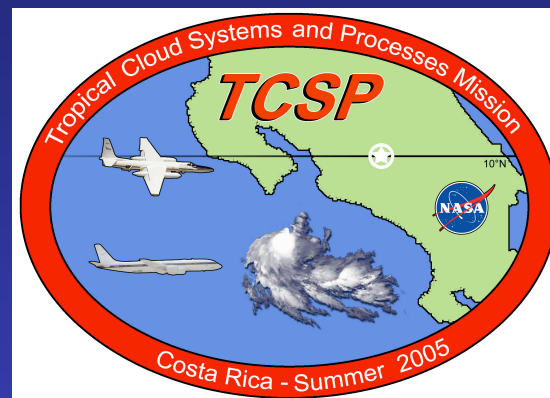
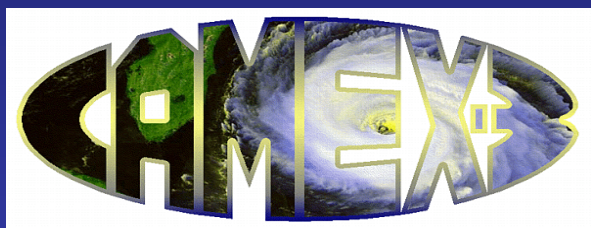


# **NASA Field Campaigns**



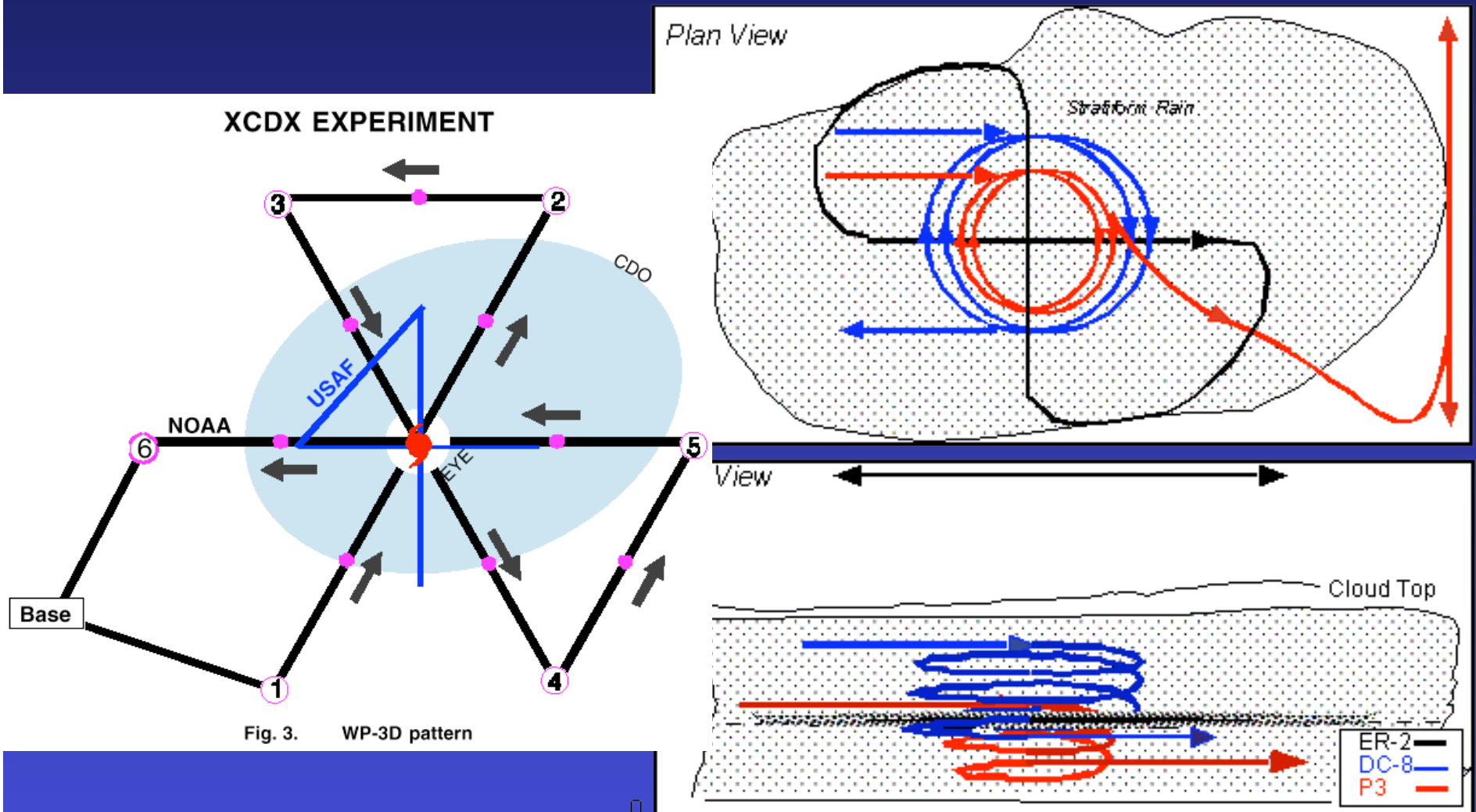
# NASA's Heritage of Hurricane Research Field Programs

- Joint partnership with NOAA HRD
- Blending of *in situ* and satellite data sets
- Improved parameterization of models
- Data assimilation to improve models
- Technology testbed (i.e. ER-2 dropsonde, Global Hawk)



# Coordinated Aircraft Sampling

Vertical Structure of Stratiform Rain  
*Lagrangian Microphysics Spiral*



# NASA's DC-8 and Scientific Serendipity



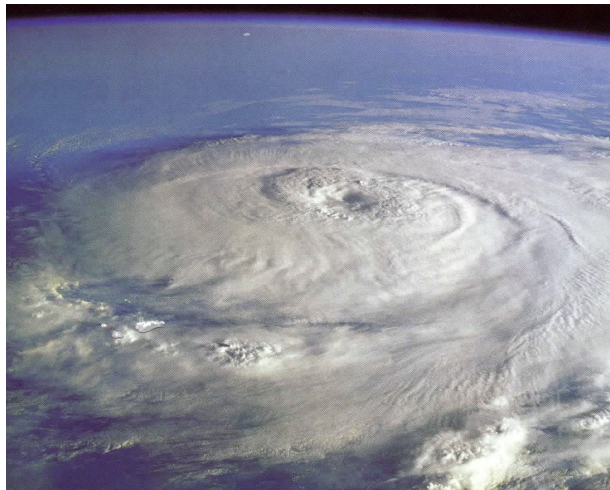
# CAMEX Scientific Missions



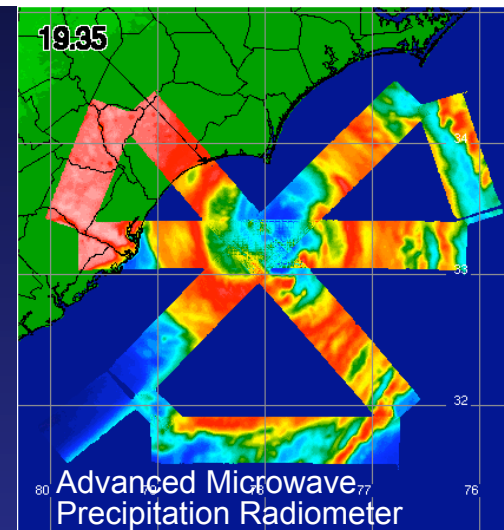
← Halverson loads a dropsonde in the DC-8 during a mission

Interior view of DC-8 scientific instrumentation





# NASA ER-2: *Virtual Satellite*



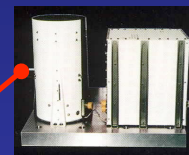
MODIS



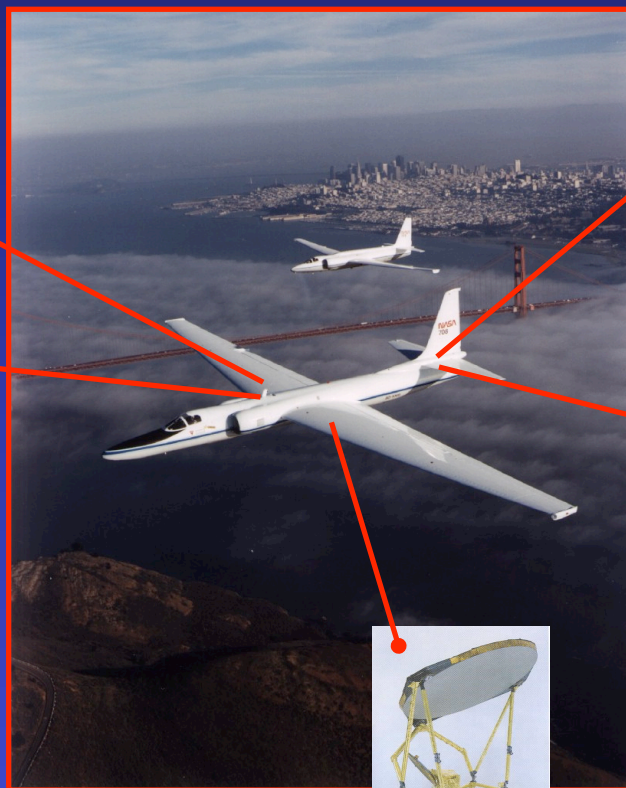
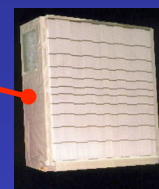
TRMM  
Microwave  
Imager



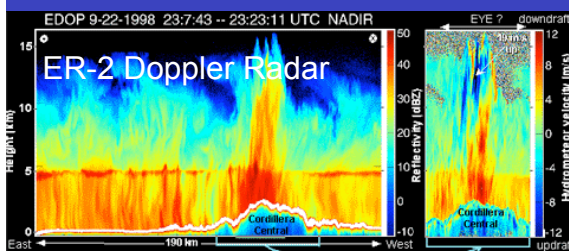
Lightning  
Imaging Sensor



Precipitation  
Radar



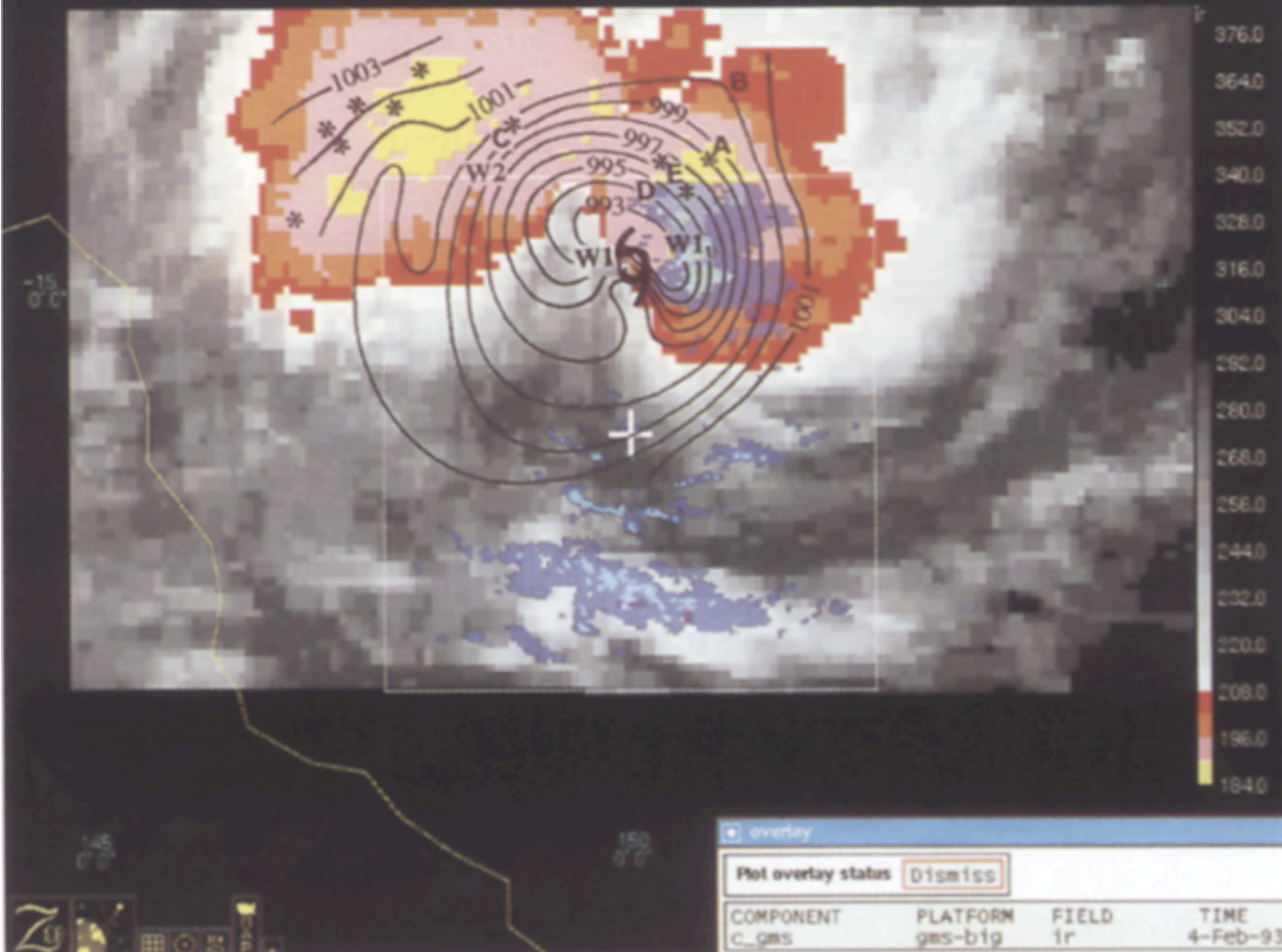
AMS-R-E





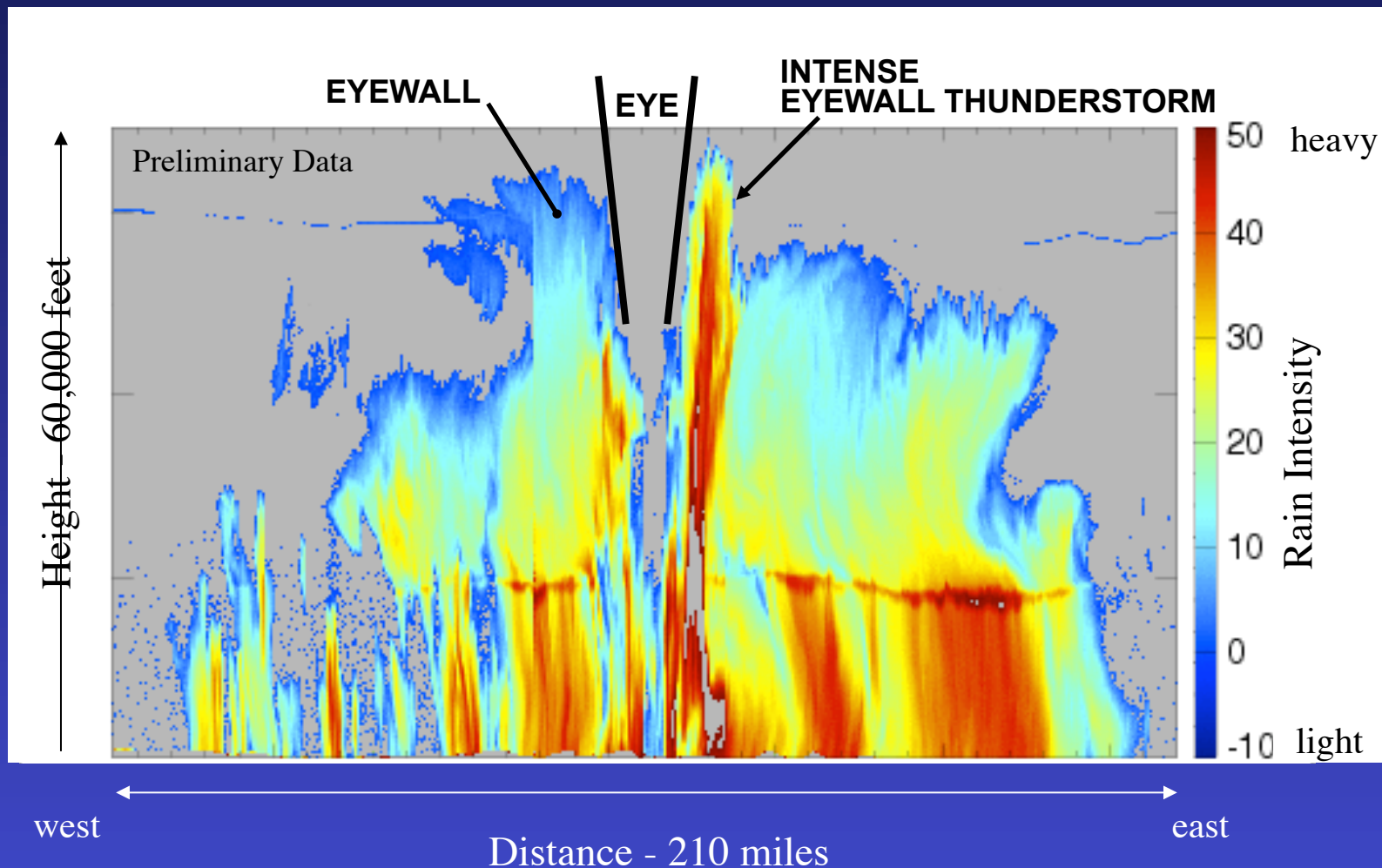
# T.C. Oliver Research - TOGA COARE

4-feb-1993,17:40:00 ir plot.



Simpson et al.,  
1997, 1998

## ER-2 Doppler Radar (EDOP) Views Detailed Super-Anatomy Of Intense Hurricane Emily During NASA's TCSP Experiment

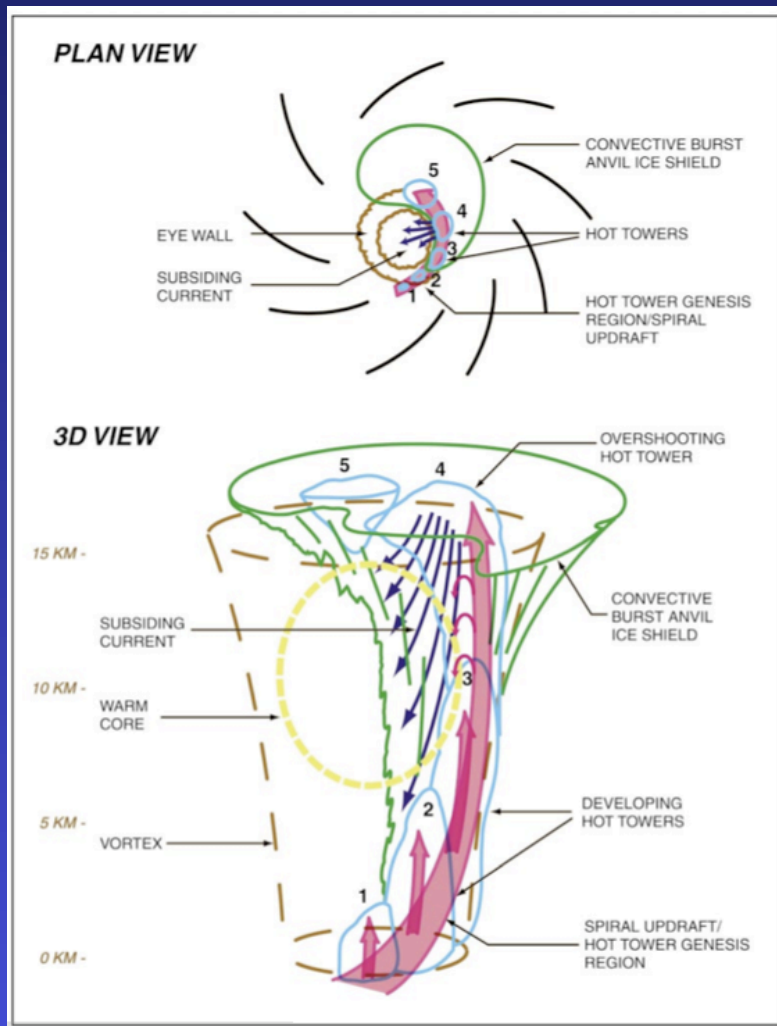


Vertical slice showing rain structure across the entire storm -  
1:30 - 2:00 AM CST July 17, 2005

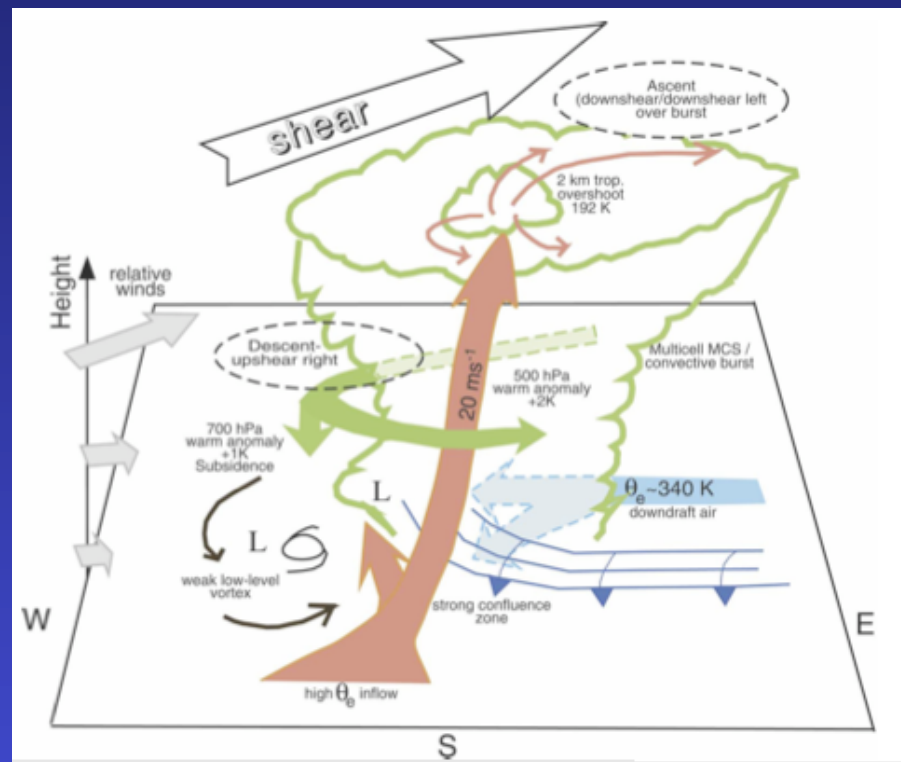
G. Heymsfield

# CAMEX: Conceptual Models for TC Hot Towers & Intensity Change

Hurricane Bonnie, 1998



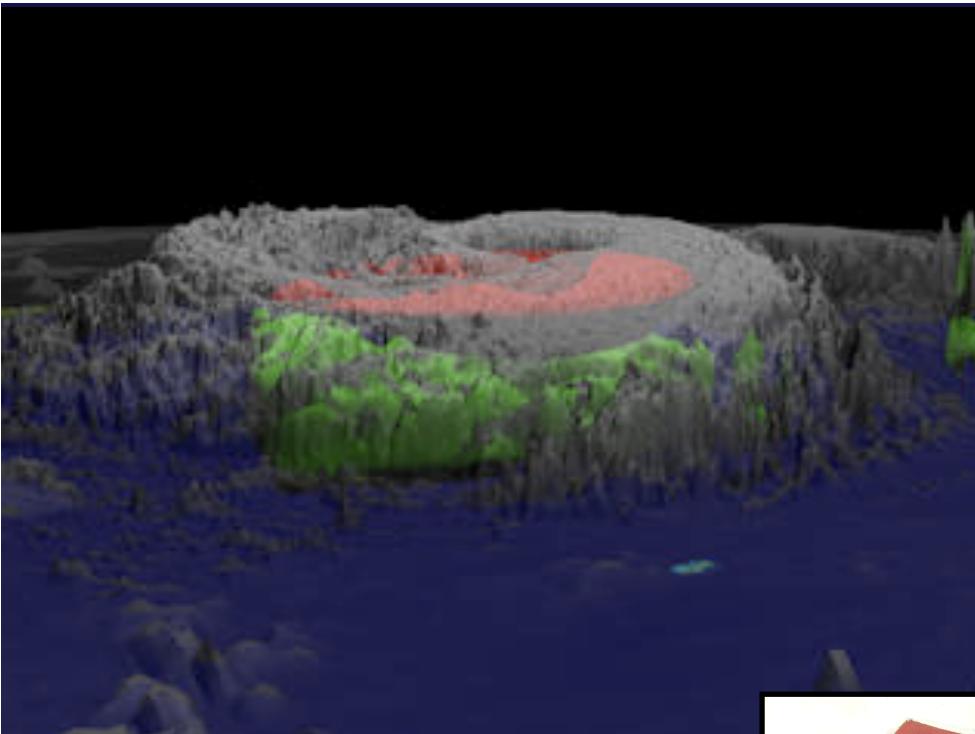
Tropical Storm Chantal, 2001



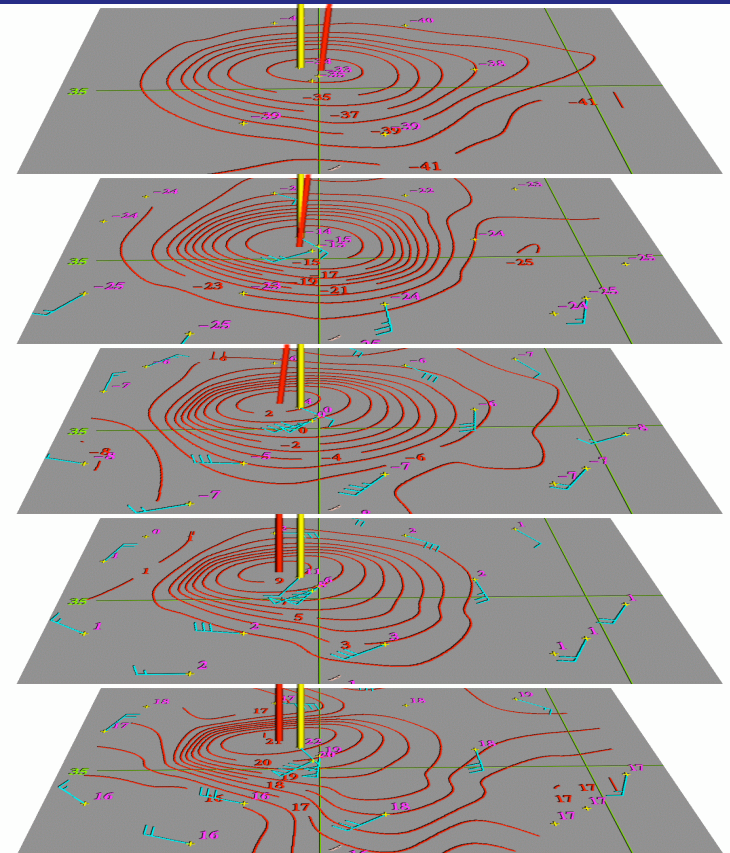
Heymsfield et al., 2001, 2006

## ER-2 Dropsonde Heritage

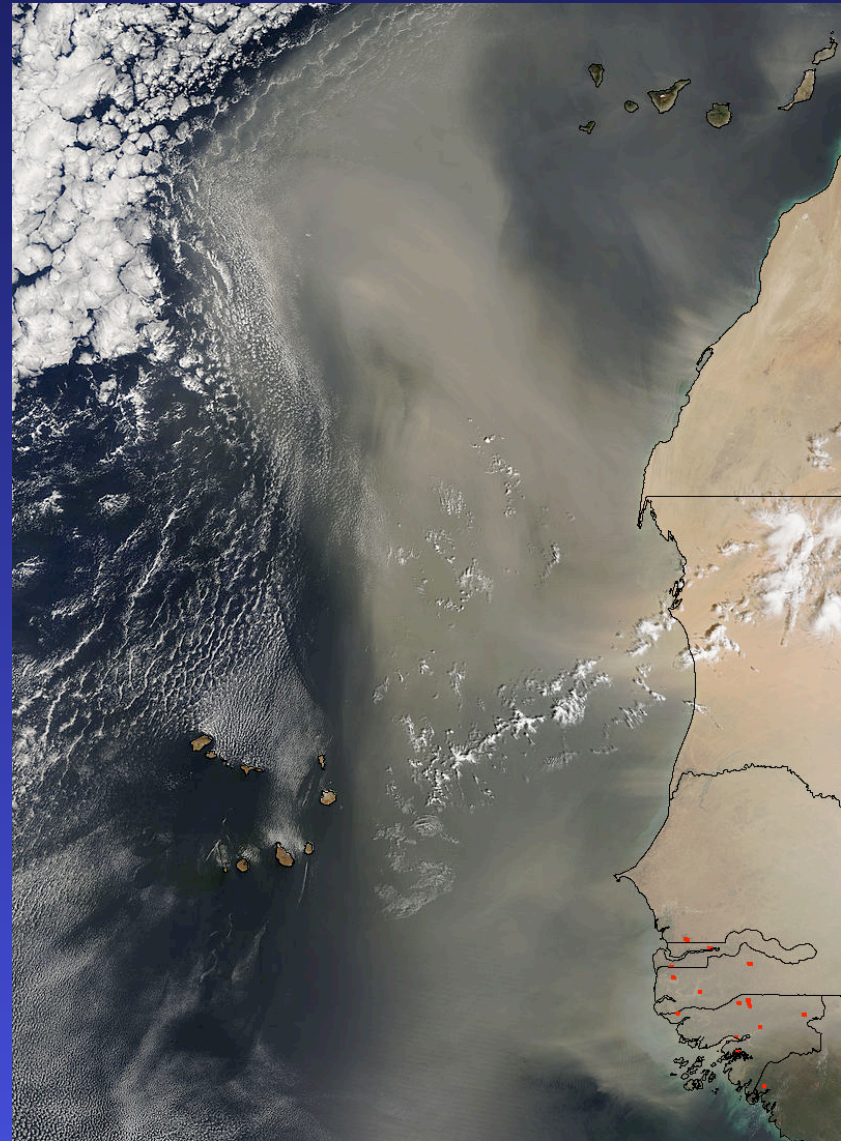
- EHAD: ER-2 High Altitude Dropsonde
- NASA CRYSTAL-FACE, CAMEX-4
- First 3-D map of warm core from 70,000' to ocean surface



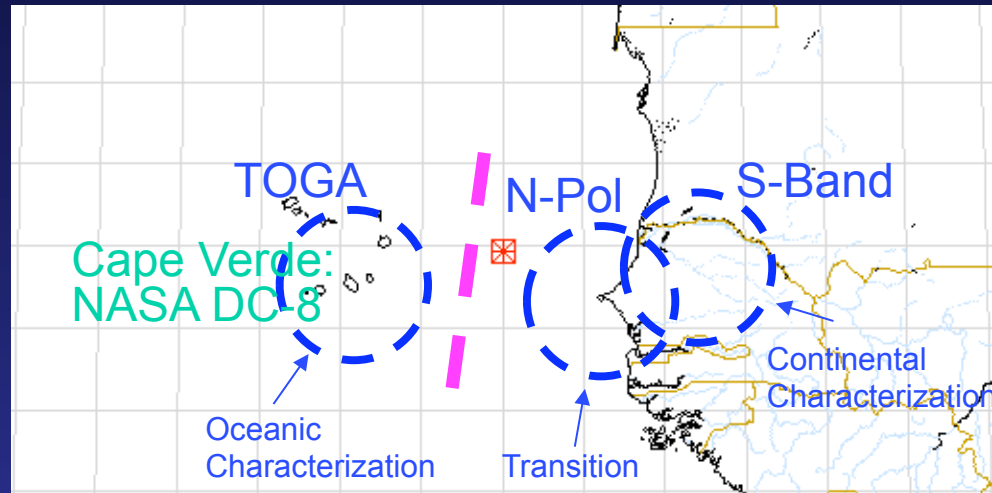
Halverson et al., 2006



African SAL: Impact on tropical cyclogenesis - uncertain, but a key component in an oceanic basin marginally suitable for hurricane generation; examine effects of SAL dust composition & stratification on microphysics, thermodynamic instability, shear, airmass dessication



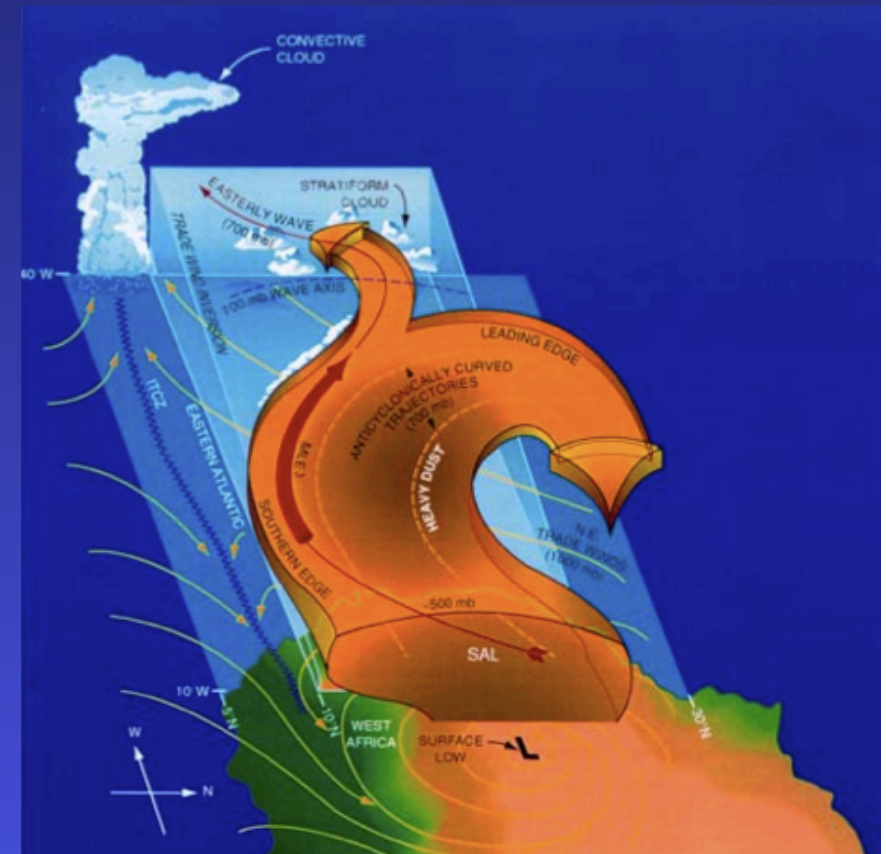
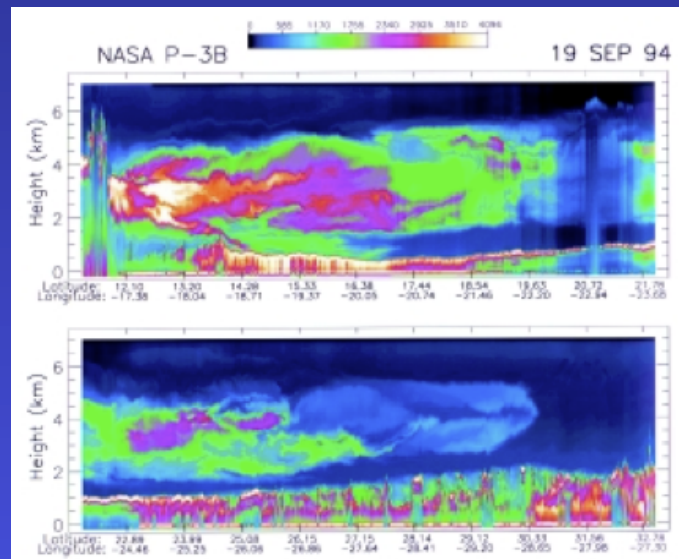
# NAMMA: Role of African Dust on TC Genesis



← Wave-Depression Transition

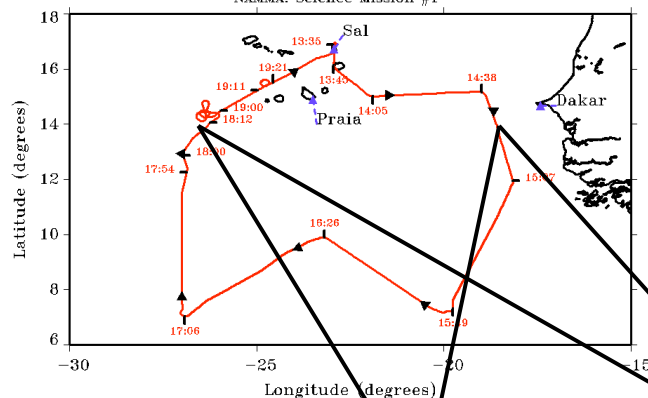


**Karyampudi et al., 1988, 1999, 2002**



LASE DC-8 Track (Flight 04) Aug 19, 2006

NAMMA: Science Mission #1



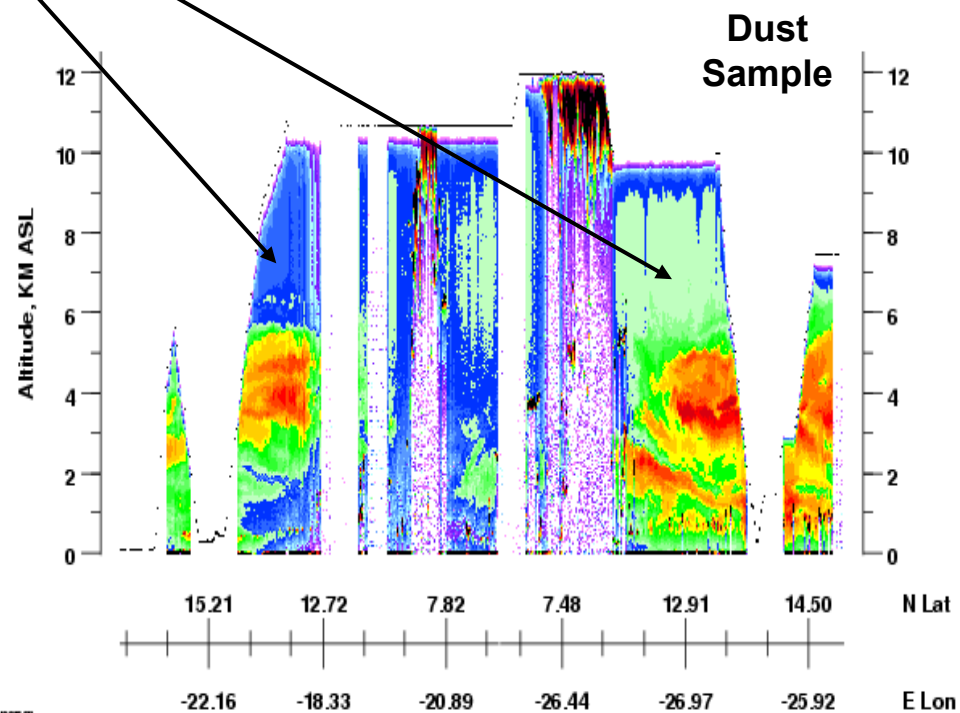
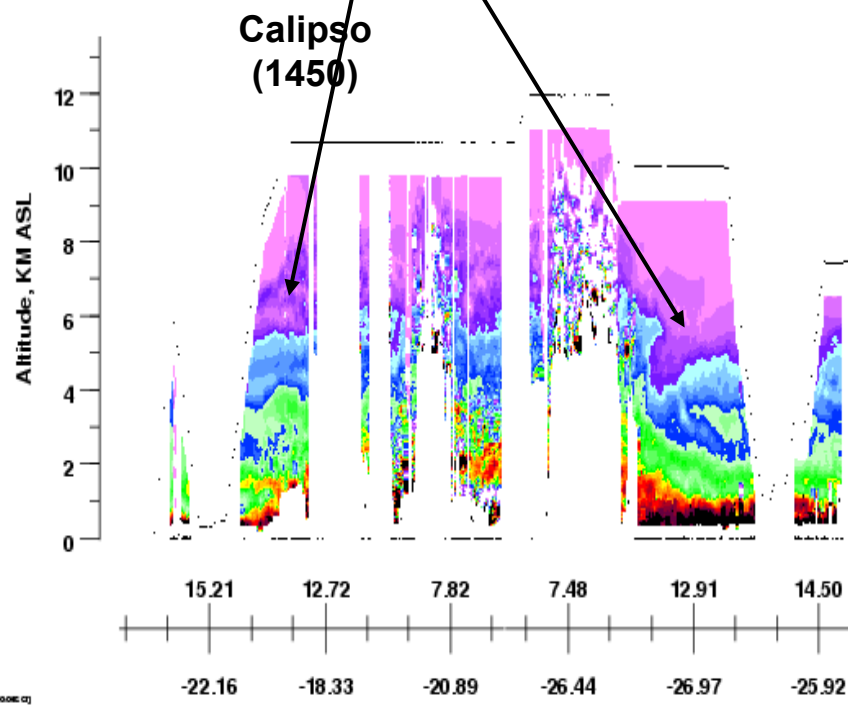
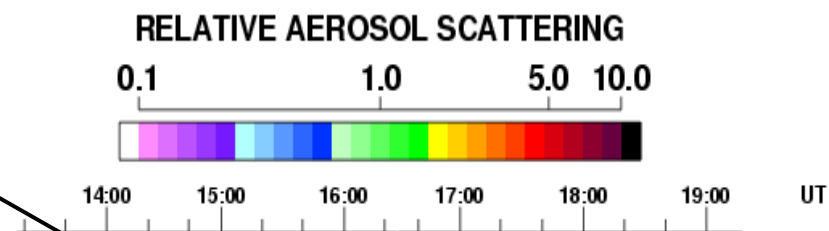
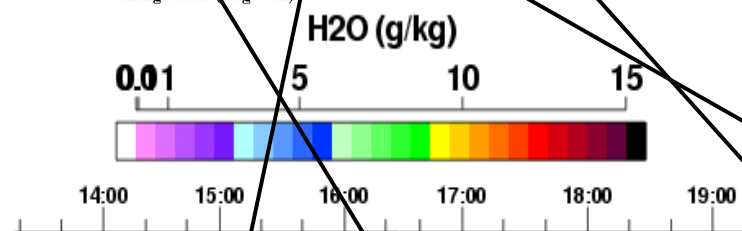
## Wave Flight [became Ernesto] 19 Aug 06 (Flt 04)

- Calipso Underflight
- Dust Sample

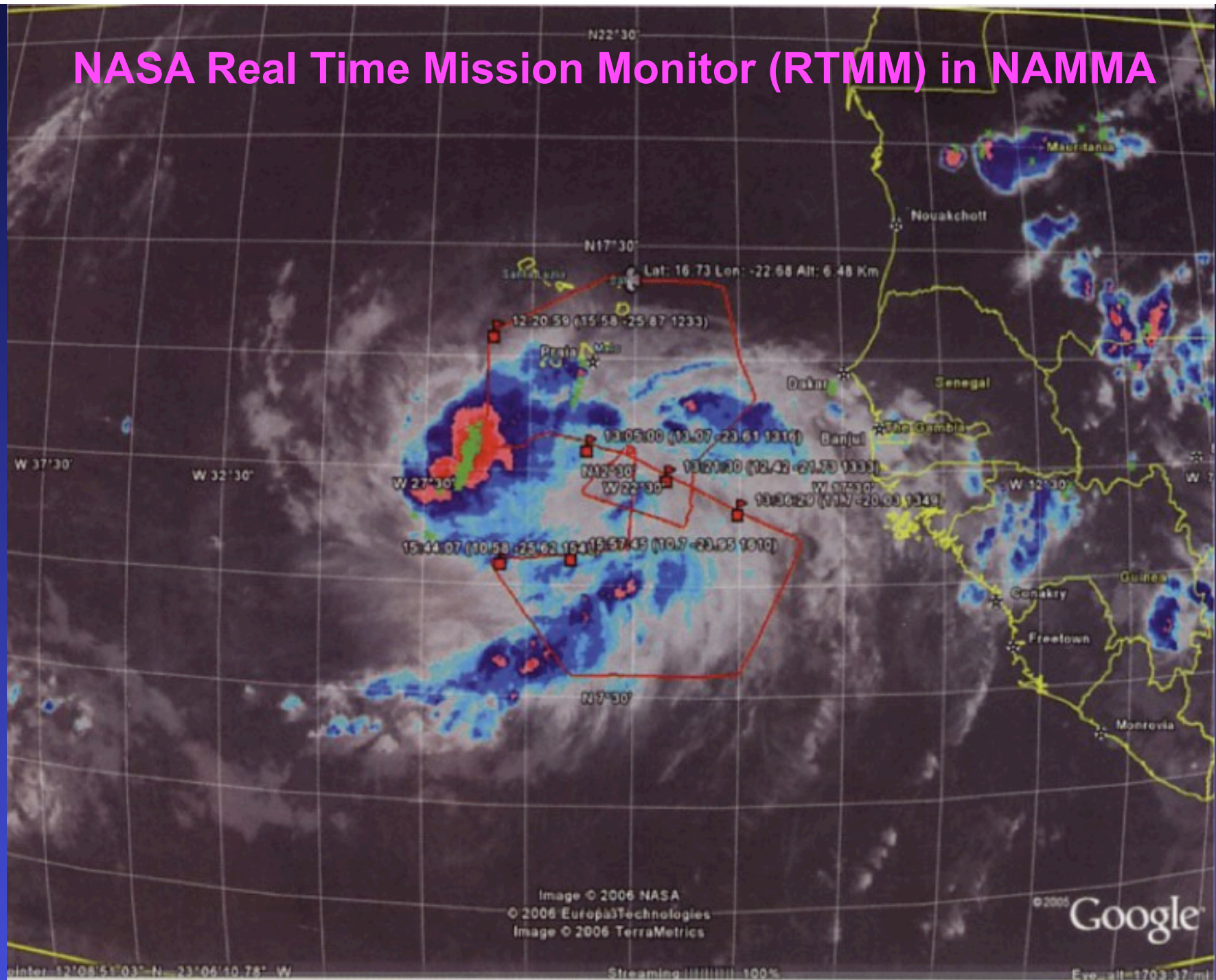
LASE/NAMMA

Flight 4

19 Aug 06



# NASA Real Time Mission Monitor (RTMM) in NAMMA

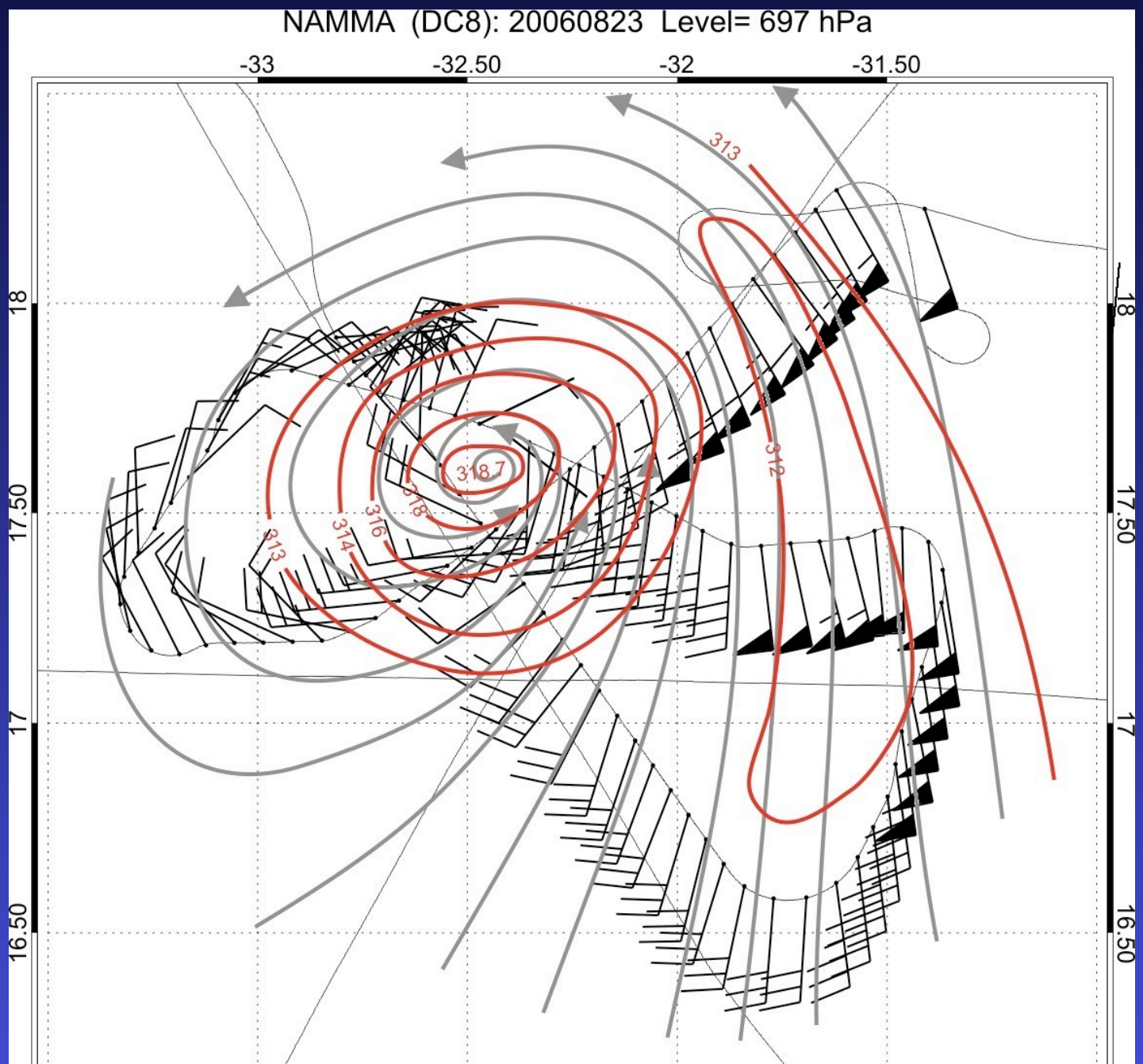


*Flight Data from  
697 hPa Module:*

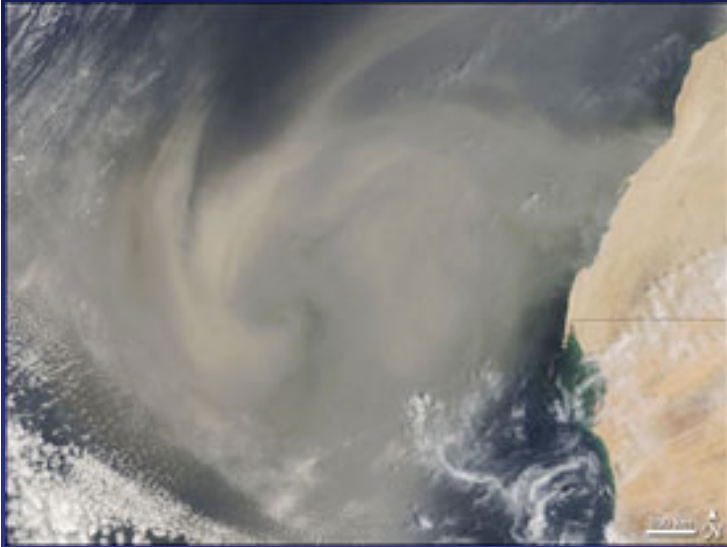
*Max Wind 63 kt;  
Temperature  
increase in  
'eye' is 6°K*

*Radius of max  
wind ~~ 40-50 km*

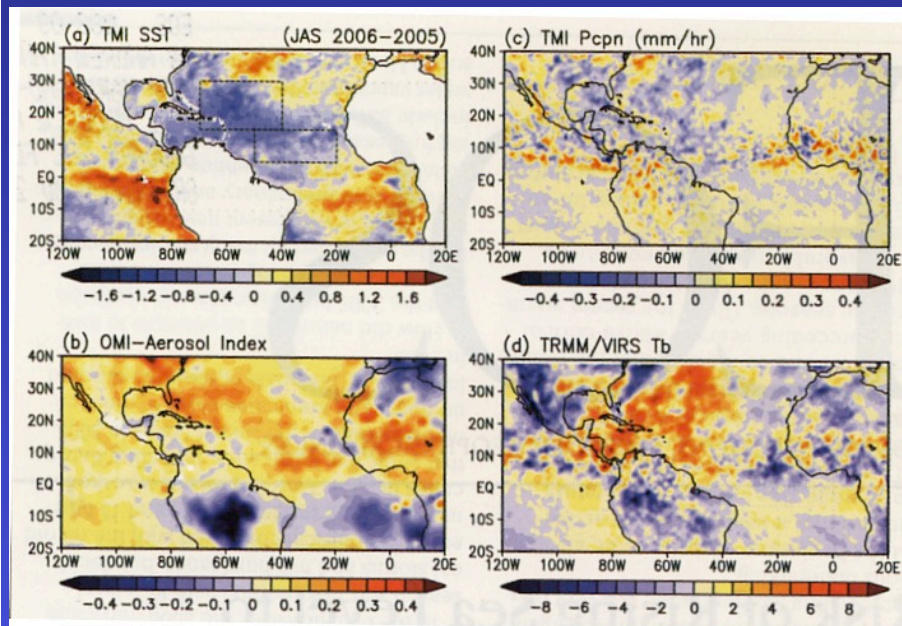
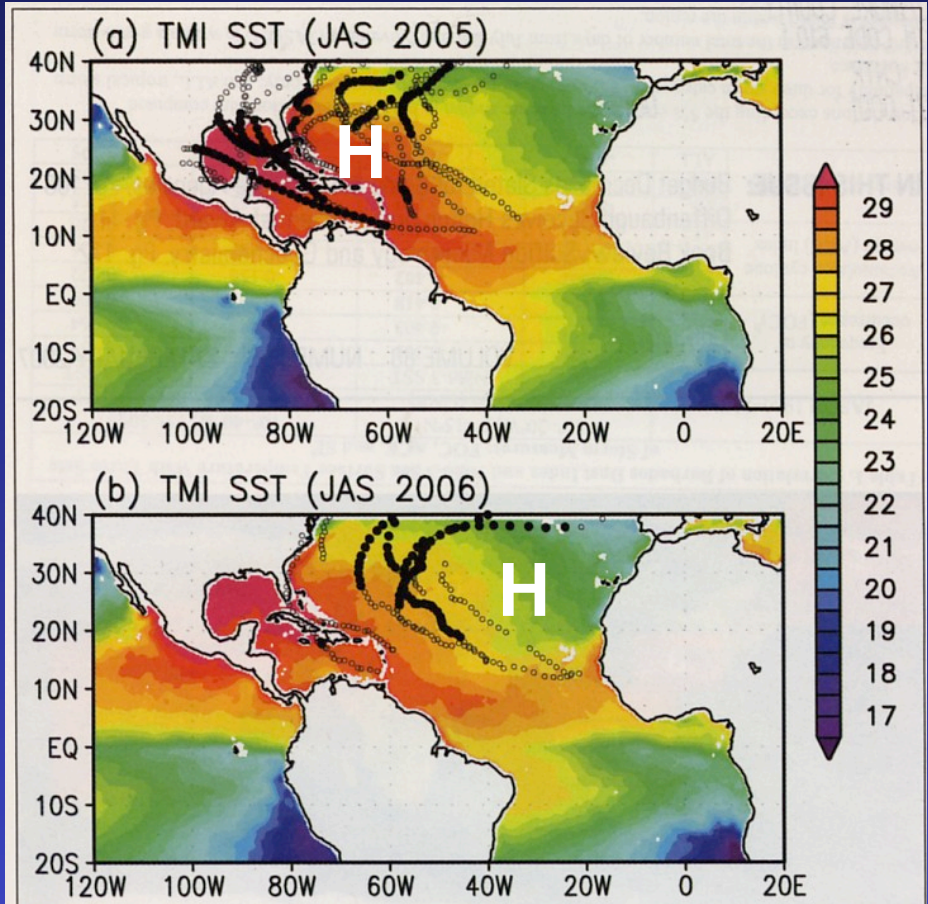
M. Douglas,  
E. Zipser



# Suppression of Atlantic TCs: African Dust



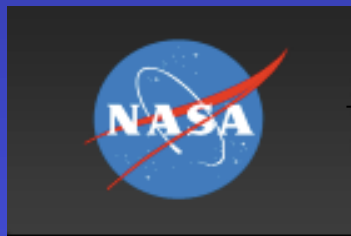
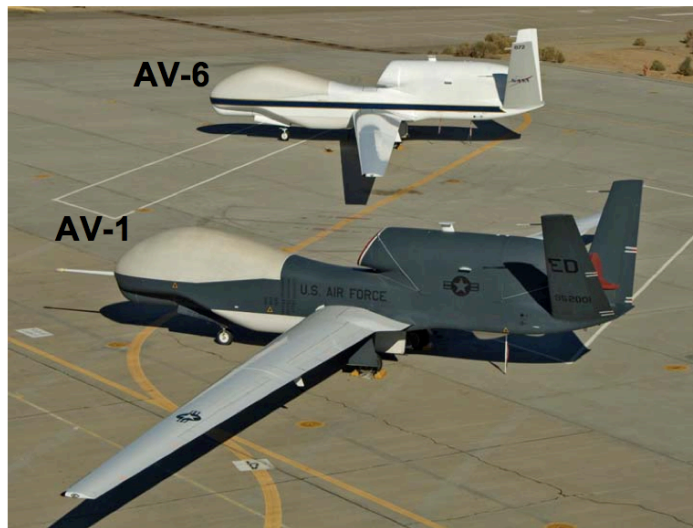
Lau & Kim, 2007



- Large amount of African dust sequestered over WATL in summer-fall, in 2006 vs. 2005
- The dust dimmed incoming solar energy, cooling the SST, reducing rainfall & storminess

# NASA GRIP (2010) - Genesis and Rapid Intensification Processes

Global Hawks

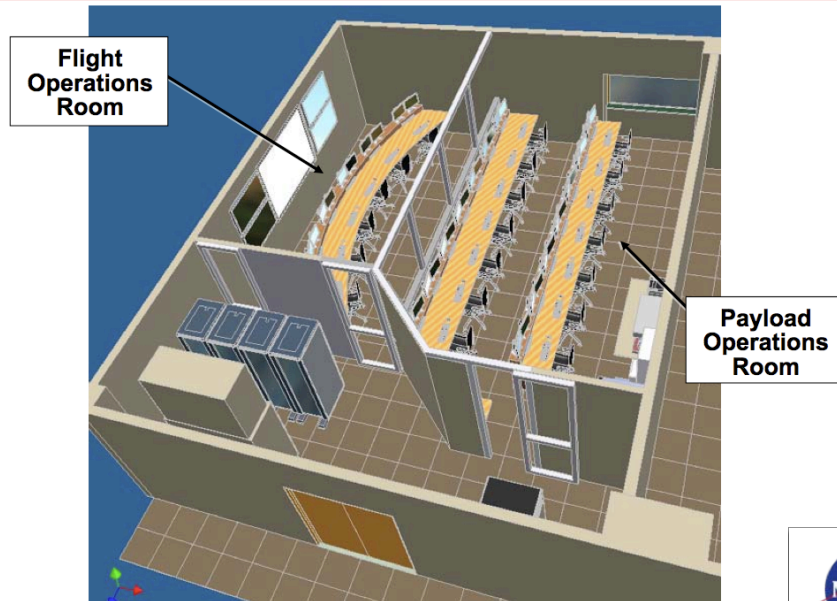


## Key Paradigm Shifts:

- Reconnaissance > Surveillance
- Geosynchronous simulator
- Telescience



## DFRC Global Hawk Operations Center (GHOC)



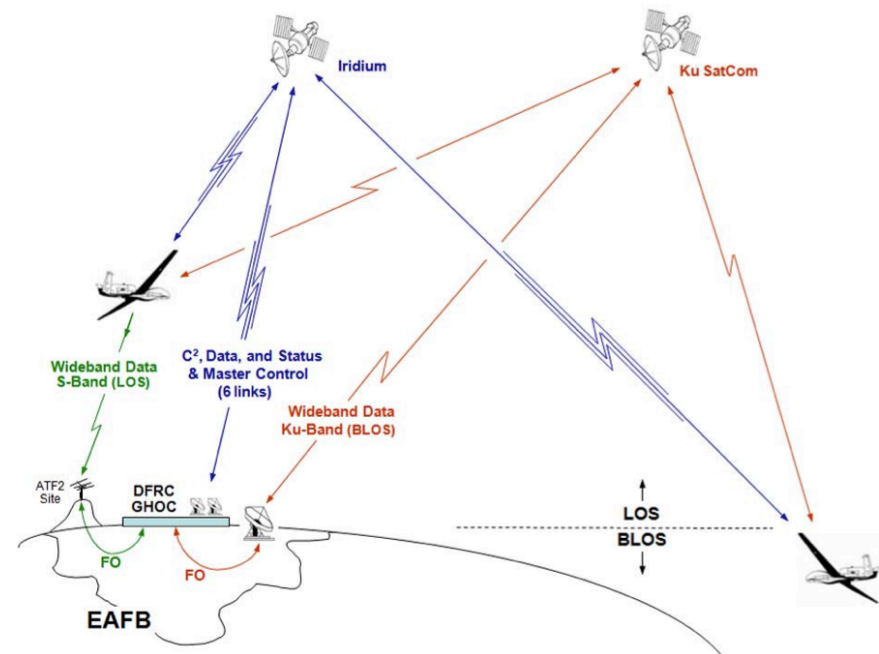
# “Telescience”

Dave Fratello, Payload Manager  
NASA DFRC

# Global Hawk



## Payload System Communications Architecture



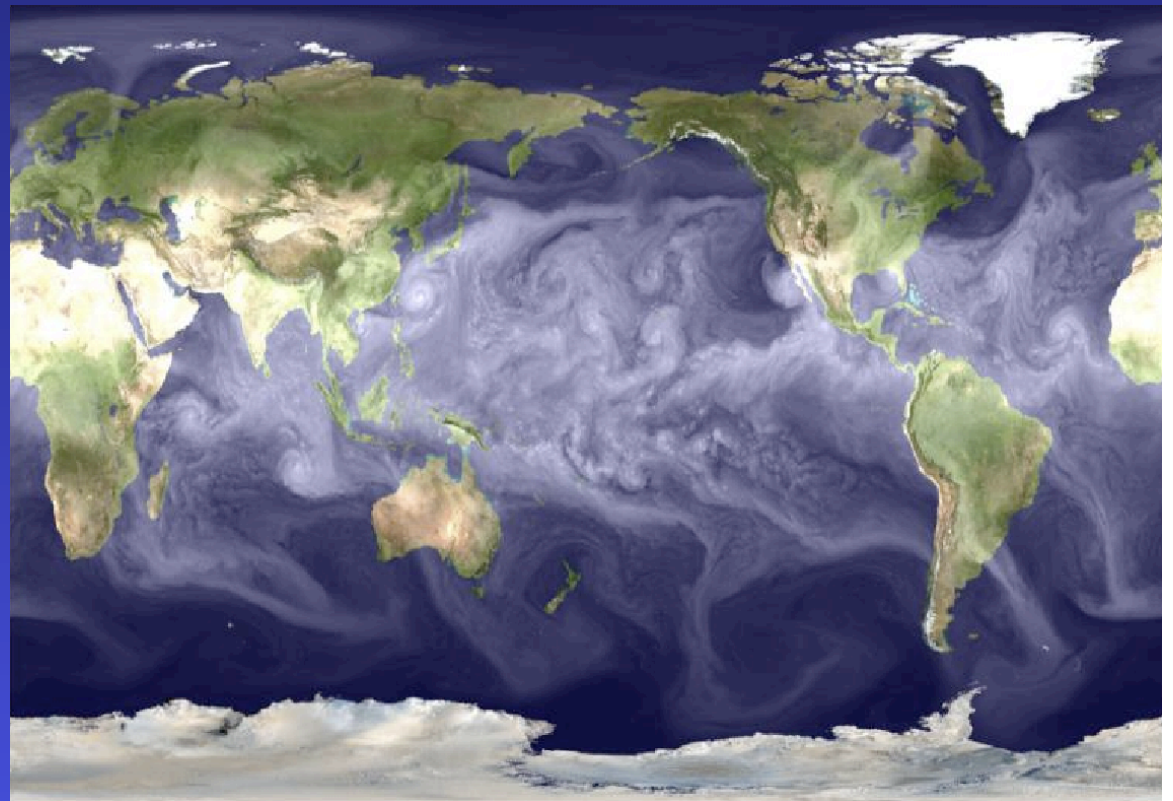
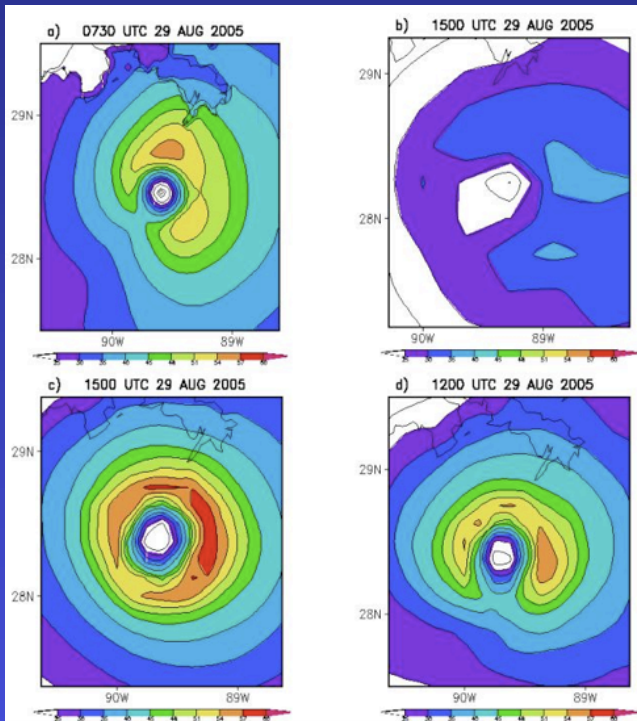
# **NASA Numerical Modeling**

# Climate Model Simulations of Hurricane Katrina



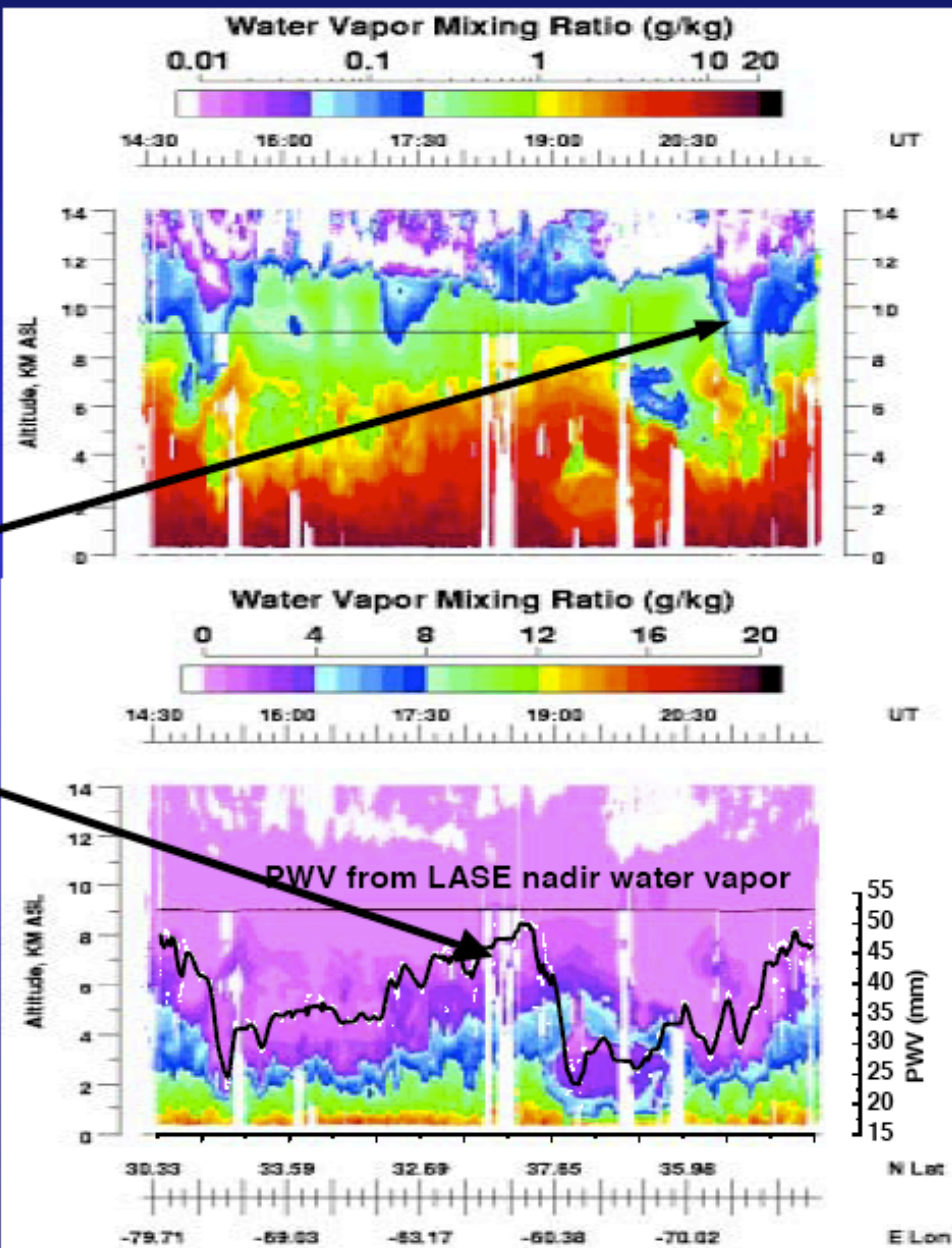
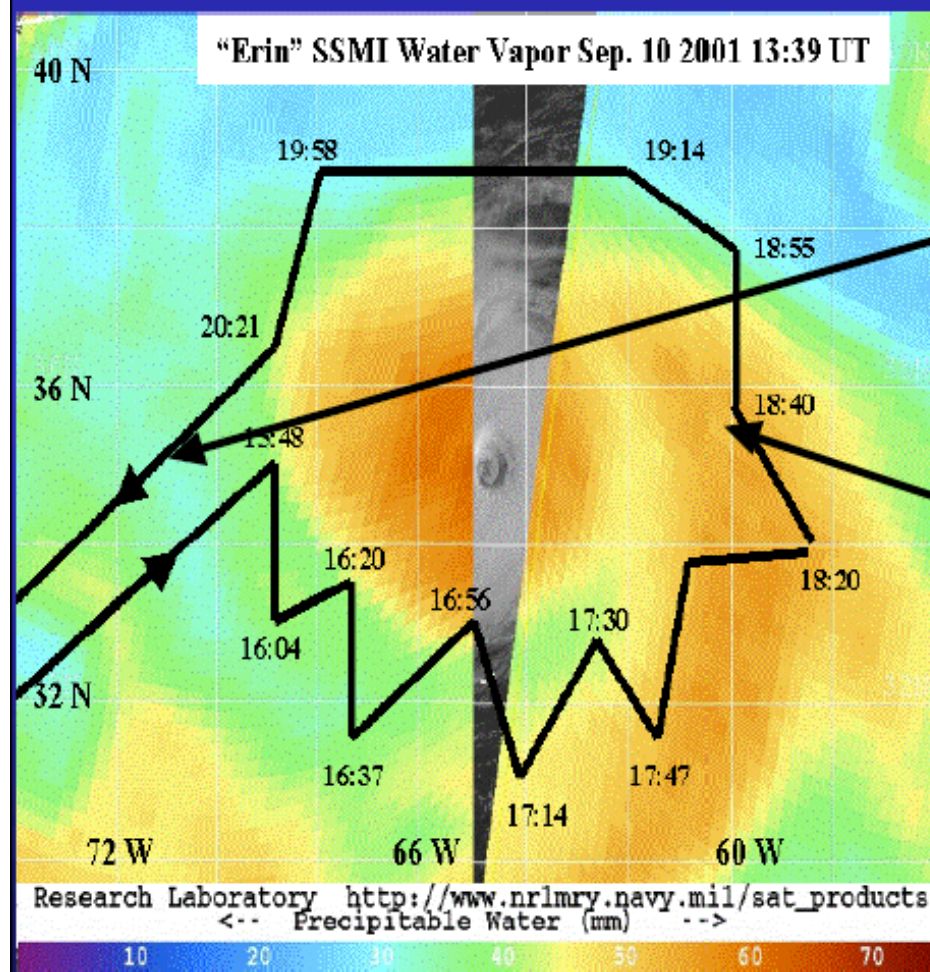
- 1/8 deg grid resolution
- simulated RMW, storm intensity, track
- cumulus parameterization not needed

B. - W. Shen et al., 2005, 2006



# CAMEX-4 Hurricane Erin "Optimal Data Assimilation" Flight

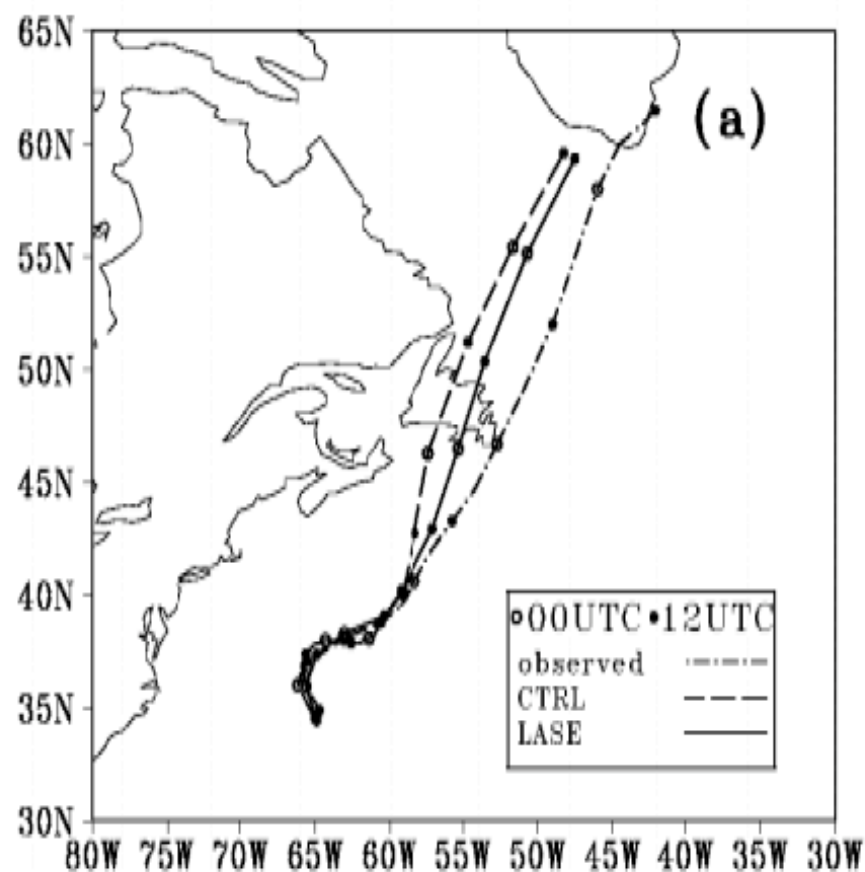
- High water vapor northeast of storm
- Mid-upper level dry region associated with cold trough southwest of storm
- Large variation in integrated water vapor



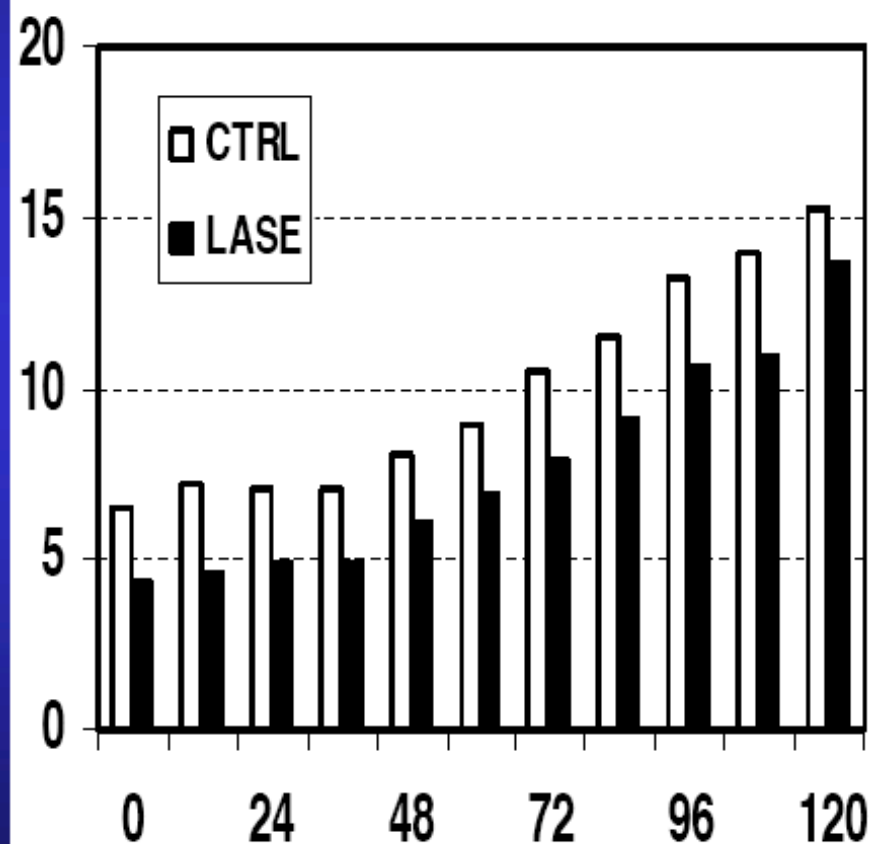
# FSU Model Results for Hurricane Erin using CAMEX-4 LASE Data

T. N. Krishnamurti

120hr forecast track of Hurricane Erin  
IC: 12UTC 10 Sep 2001

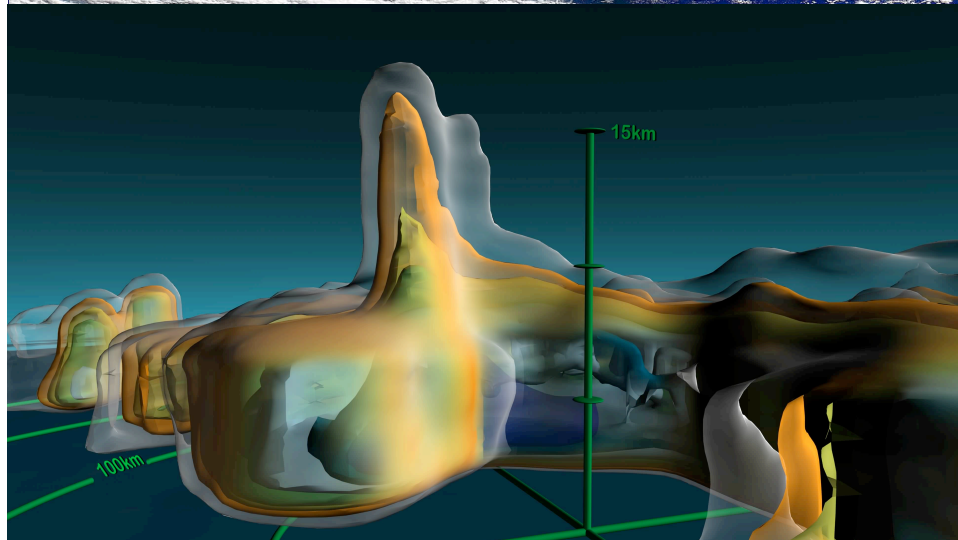
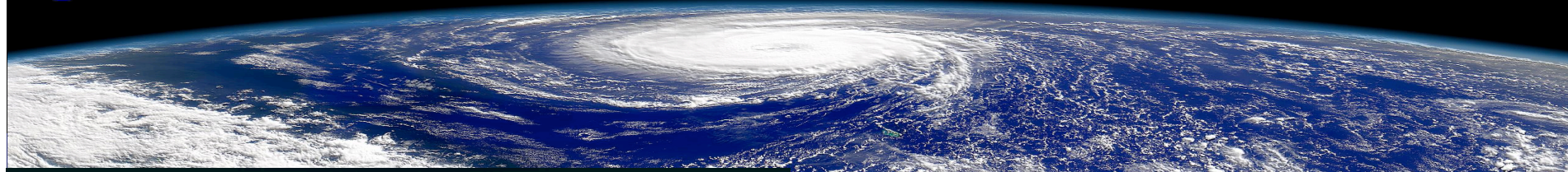


Intensity errors (in m/s) of Hurricane Erin  
IC: 12UTC 10 Sep 2001

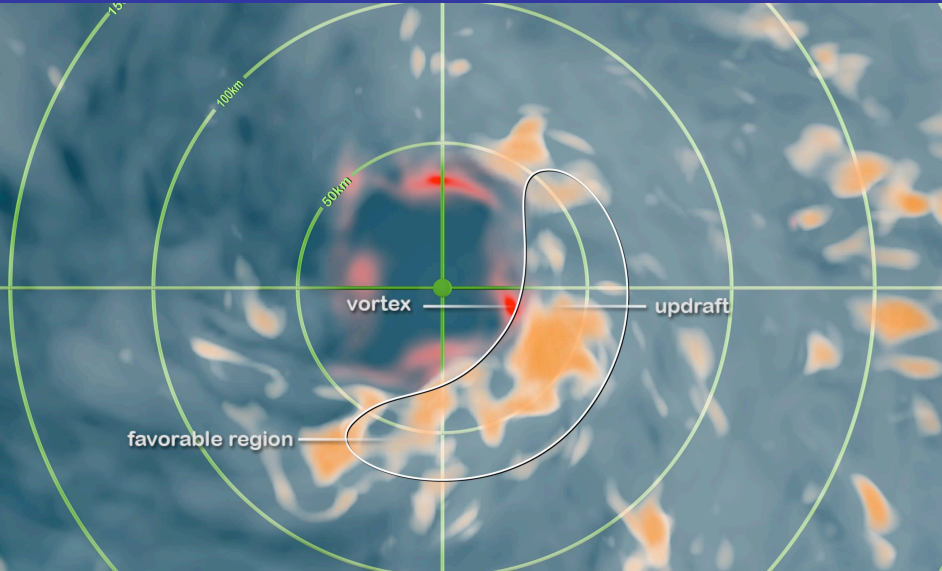
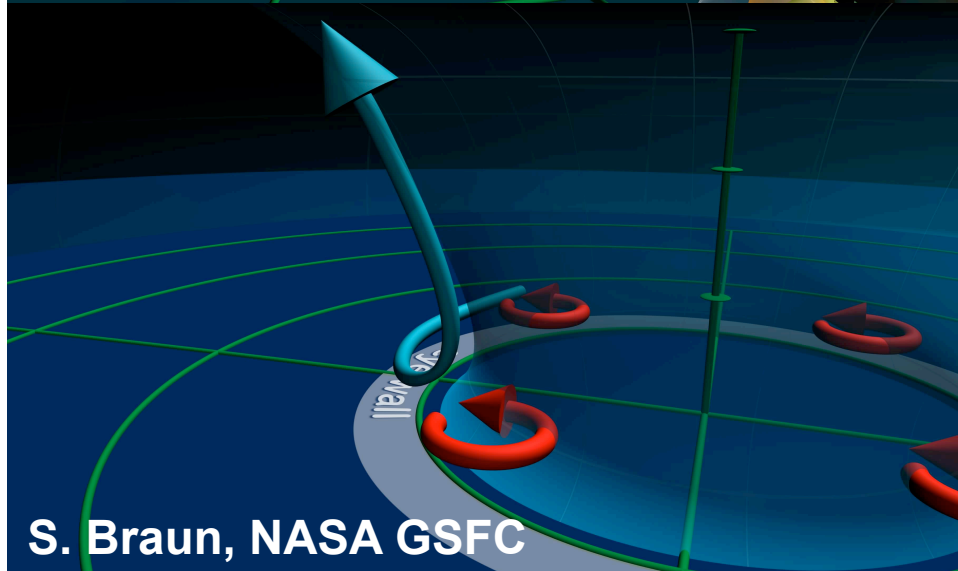




# Numerical Simulation of TC Hot Towers



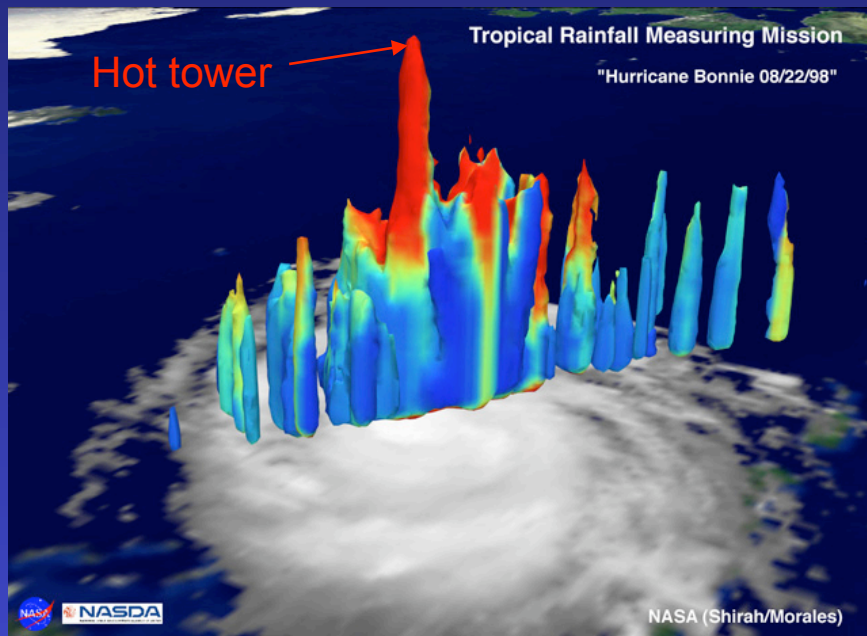
TRMM observations and numerical modeling reveal the role of hot towers in hurricane intensification and the processes that control their formation and movement



S. Braun, NASA GSFC

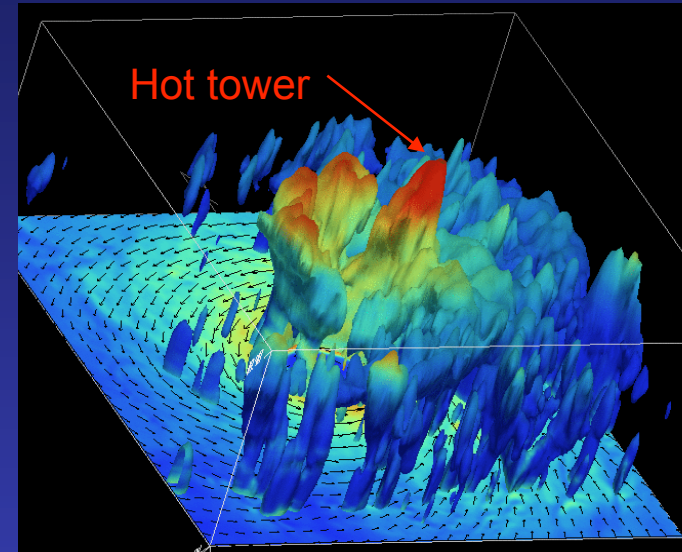
# Hurricane Hot Towers

- TRMM observations of Bonnie and other hurricanes show towering thunderclouds, called hot towers, often signify the onset of intensification.



*Hurricane Bonnie, 8/22/1998*  
*Tallest tower is >15 km in height*

*High resolution (MM5) computer simulation of Hurricane Bonnie*



- Model reveals that intense vortices in the eyewall may help formation and control movement of hot towers
- Tower updrafts account for more than half of the cloud condensation in the eyewall.



# Happy Hurricane Hunting, NASA!



*Special Thanks to  
Dr. Ramesh Kakar*



[http://www.nasa.gov/mission\\_pages/hurricanes/main/index.html](http://www.nasa.gov/mission_pages/hurricanes/main/index.html)